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OPTIMIZATION OF COMPUTER AUTOMATED ULTRASONIC INSPECTION SYSTEM

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This report describes the work conducted on a program to optimize the hardware and software of a computer automated ultrasonic inspection system which was developed under a previous Air Force Contract F33615-72-C-1828. The hardware modifications included improvements of the scan drive mechanism to increase inspection speed and development of improved ultrasonic circuitry to perform zone scanning inspections. Software developments included: (1) implementation of the zone scanning inspection method, (2) programs

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for signal processing to enhance random flaw detection, and (3) development of a Computer Aided Design Data Control (CADDC) method to interface the inspection system with data generated by Computer Aided Design (CAD) approach to component design.

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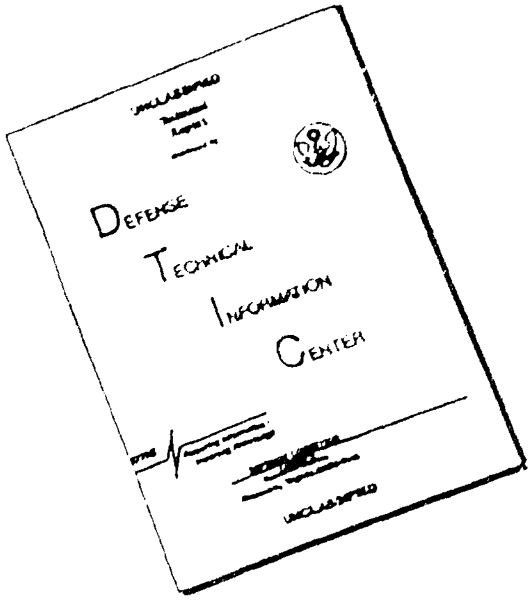

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FOREWORD

This final technical report describes the optimization of a computer automated ultrasonic inspection system which was developed under a previous Air Force Contract F33615-72-C-1828. The present work is supported by Air Force Contract F33615-76-C-5104 and it covered the period from June 1976 to October 1978.

This work was sponsored by the Air Force Materials Laboratory, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio. The Air Force project engineer for this contract is Mr. Ken Shimmin of the Nondestructive Evaluation Branch of the Metals and Ceramics Division.

This program was performed in the NDE group of the Materials Technology Section of the Structures and Design Department of Fort Worth Division, General Dynamics Corporation, Fort Worth, Texas. Dr. Bill G. W. Yee was the program manager with Dr. J. C. Couchman as the principal investigator for technical development. The key contributors to the program were:

Mr. J. R. Bell - Overall Systems Optimization
Mr. G. Arnett - Software Development
Mr. A. H. Gardner - Electronics and Ultrasonics Development
Mr. A. R. Robinson - Mechanical Scanner Improvement
Dr. F. H. Chang - Ultrasonics and Integration

This program was ably supported by Pattern Analysis and Recognition (PAR) Corporation as subcontractor and Dr. G. Jarvis as task leader for PAR.

This final report was submitted by the author on September 13, 1978.

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SUMMARY

In a previous AFML contract (F33615-72-C-1828) to General Dynamics' Fort Worth Division, a five axes computer automated ultrasonic inspection system (CAUIS) was developed and demonstrated to successfully inspect semi-complex aircraft structures. The results of this work were documented in the final contract report (AFML-TR-75-82) (Ref. 1). Although the CAUIS was capable of inspecting engine disks (sonic shape) and simple aluminum forgings with more than 50% reduction in inspection time over conventional mechanized ultrasonic inspection systems, it was not optimized for routine inspection and required considerable operator interface for the inspection of complex aircraft structures. The conclusions and recommendations of contract F33615-72-C-1828 are repeated in Appendix A of this report for easy reference.

The objective of this contract is to optimize the hardware and software of the CAUIS to inspect complex and near-net shape airframe components. To achieve this objective, both hardware and software modifications and developments were conducted. The hardware modifications included increasing the X and Z axes scan speeds from 4 and 3 inches per second to 10 and 4 inches per second respectively. The Y-axis scan speed was already at 10 inches per second. The rotate (θ) and tilt ($\emptyset$) accuracies were improved from ± 1 degree and $\pm$ 1.5 degree to ± 0.4 degree and $\pm$ 0.1 degree respectively with the implementation of a new gimble assembly. Furthermore, software was developed for vector scans in the X, Y, and Z planes at speeds of 10 inches per second.

Several mechanical and software approaches were evaluated for scanning of complex near-net shapes. The mechanical methods evaluated include:

M1) mechanical probe with microswitches
M2) capacitance probes
M3) ultrasonic transducer arrays
M4) eddy current proximity sensors
M5) laser optical sensors

Software control methods evaluated include:

S1) numerical control tape (NCT)
S2) computer aided design data control (CADDC)
S3) ultrasonic zone scanning (UZS)

The methods evaluated that combine both software and mechanical methods include:

SM1. vector drive with maximization of top surface ultrasonic signal
SM2. vector drive with self-organizing control

Scanning methods M3 and SM1 were developed in the previous AFML contract and optimized in the present contract. Methods S2 and S3 were developed in this contract. The CAUIS has the capability to scan complex airframe components with any one of these five methods. However, the ultrasonic zone scanning (UZS) or S3 methods is the most versatile and practical and it was selected to scan the two demonstration components of this contract. Component I is a F-111 Al landing gear forging (rough) and component II is a near-net shape F-16 Al isothermal bulkhead. A picture of each component is shown in Section IV of this report. The development of electronics, ultrasonics, and software for the implementation of the UZS method is described in detail in Section V of this report.

The computer aided design data control (CADDC) method was developed by Pattern Analysis and Recognition Corp. with the assistance of General Dynamics. The CADDC method makes use of the data generated when a component is designed by the Computer Aided Design (CAD) approach. The wing attach fittings of the F-16 fighter were designed with the CAD approach. Thus data was available for this component for the CAUIS to follow its contour for ultrasonic inspection. However, the CADDC capability was not demonstrated because the component was eliminated when the scope of this contract was reduced.

Several signal processing schemes were developed to reduce and eliminate ambiguities in the ultrasonic signals to display only flaw or defect signals. Some of these schemes included: amplitude filter, spatial filter, consecutive filter, and adjacent scan line filter.

By using some of these signal processing schemes with the UZS method, a near-net shape airframe component (the F-16 bulkhead, with radii from 1/8 to 1/2 inch, flange thickness in the pockets from 0.09 to 3/8 inch, and maximum section thickness of 5.16 inches) was successfully inspected at ultrasonically average scan speeds of more than six inches per second.

SECTION I

INTRODUCTION AND RATIONALE

There are two primary motivations for the computerized automation of ultrasonic inspection of high-performance aircraft structures. One is cost and the second is the combinations of damage-tolerance requirements and the application of fracture mechanics to aircraft structural design. The former requires very little elaboration. The cost of both material and labor continues to escalate year after year. Automation of labor-intensive operations, such as ultrasonic inspection, offers an opportunity for cost savings. Furthermore forgings, castings, and powder-compacted near-net-shape aircraft components can not and are not being inspected with ultrasonic techniques. Today, they are inspected primarily with liquid penetrant, magnetic particle, or eddy-current techniques for near-surface defects after they have been machined to final shape. Rejectable defects detected during post machining inspection can result in the loss of considerable machining time or dollars. Internal defects, particularly for powder-compacted structures, can not be detected by these techniques and are quite amenable to detection by ultrasonic techniques.

The second motivation to computer-automated ultrasonic inspection is to meet damage tolerance and fracture-mechanics requirements. These requirements affect both performance and cost. Today, Air Force Damage Tolerance Specification MIL-A-83444 requires that defects of specified sizes in all fracture-critical parts must be detected with a minimum of 90-percent probability at a 95-percent confidence level. These minimum-defect sizes that are assumed to exist initially affect the weight of the structure directly, thus the cost and performance of the aircraft. The smaller the initial defect size is, the lighter the structure will be; thus, the aircraft will require less material and consume less fuel. However, manual and mechanized ultrasonic inspection do not have high reliability of defect detection with equipment limitations, geometrical constraints of the structure, and a host of human factors contributing to the problem of detection reliability. Again, computer-automated ultrasonic inspection offers

an opportunity to achieve the necessary high reliability of defect detection and keep the inspection cost low.

Realizing these needs, the Air Force Materials Laboratory began to initiate R & D programs to develop computer automation of ultrasonic inspection. One of the earliest programs aimed toward computer automation of ultrasonic inspection was conducted by International Harvester (Ref. 2) with AFML sponsorship. The objective of this program was to rate the cleanliness of thick-section steel stocks, and the computer provided primarily signal-processing capabilities.

In 1971, General Dynamics was contracted by NASA/MFS (Ref.3) to develop a computer-automated ultrasonic-weld-inspection system. This system provided real-time control of an X-Y (two axes) scanner as well as real-time display of inspection results and hard-copying capability. Also in the 1970-1971 period, computer-automated ultrasonic-inspection systems were being developed at Sandia Laboratory (Ref. 4) and at the Union Carbide Corporation, Nuclear Division, Oak Ridge Y-12 Plant (Ref. 5 and 6). In 1972 TRW (Ref. 7) was contracted by AFML to develop a computer-automated system to inspect large-diameter titanium billets. One of the main objectives of this program was to develop an ultrasonic-pulser/receiver system capable of penetrating several inches of titanium. A more recent development is a system by Rockwell International, Atomics International Division (Ref. 8). This system was designed primarily to inspect thick sections of pressure vessels.

All the systems described above use the computer primarily for processing and analysis of ultrasonic signals. Some of the systems provide the additional capability of controlling the transducer scanning system in the X-Y plane.

In 1972, AFML sponsored the first automated ultrasonic inspection system (CAUIS) capable of controlling five axes for the inspection of complex components. This program was conducted by General Dynamics and the capabilities and limitation of the CAUIS is fully documented in Ref. 1. Following this program, AFML sponsored a program with the Pratt and Whitney Division of United Technology Corp. to apply a CAUIS for production inspection of near-net turbine disk shapes (Ref. 9). Both General Dynamics and TRW supported Pratt & Whitney as subcontractors in the developmental efforts of this program.

The intent of this contract is to optimize the CAUIS developed by General Dynamics in AFML Contract F33615-72-C-1828 to inspect complex near-net-shape airframe components. This final report describes the optimization effort, the capabilities, and limitations of the optimized CAUIS. The subcontract work of Pattern Analysis and Recognition Corp. for this program is described in a final report to General Dynamics (Ref. 10).

SECTION II

PROGRAM OBJECTIVES AND APPROACHES

The objectives of this program were to develop strategies, designs, software, and procedures to optimize the prototype CAUIS for complex near-net-shape airframe components. This program was divided into three phases, with test and evaluation of the system performance on typical aircraft structural components occurring at the end of each phase. Each phase centered around an increasingly more difficult component geometry. The prime purpose of the three phases was to allow for decision points to evaluate the progress and the technical obstacles which remain. This work was performed primarily by General Dynamics with Pattern Analysis and Recognition Corporation as a sub-contractor over a two-year period. The end product of each phase was a demonstration of the optimized CAUIS to adequately inspect the selected component.

The technical approach that was followed in the performance of this program began with the selection of airframe structural components for each of the three phases with Component III for Phase III being the most complex one. Component III contained some of the following characteristics:

1) Pockets of different depths
2) Web with different thicknesses
3) Radii from 1/8 inch and larger
4) Flange with different thickness
5) Holes
6) Curved surfaces.

Following component selection, the next step was the development and modification of hardware and software to adequately inspect these components. Specifically, contour following or scanning schemes must be developed to inspect these components with an average scan speed of six inches per second and with an index step such that a 0.05-inch-diameter flaw or larger be detected reliably. Also, such a flaw must be detectable when located 0.05 inch beneath the surface.

Other specific objectives of this program included

1) Software modification for compressing the stored inspection data, providing fast access to inspection data, and providing an easily interpreted presentation

2) Strategy and procedure development for minimizing operator - system interaction

3) Location indication of defects relative to the component coordinates instead of the ultrasonic tank coordinates

4) Automatic and computer-controlled calibration routine development for evaluating the transducer, ultrasonic, and electronic system performance.

SECTION III

COMPONENT GEOMETRY DEFINITION

The three components selected for demonstration include (1) an F-111 landing-gear forging, (2) an F-16 wing-attachment component, and (3) an F-16 isothermal-bulkhead forging.

3.1 Component I

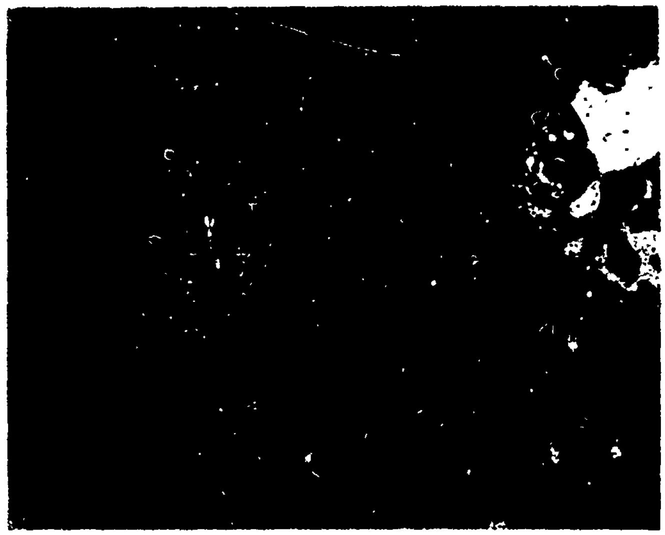
The F-111 landing-gear forging that was chosen as component I contains 13 flaws. Ten of these are flat-bottom holes, two are holes drilled at about 30^{o} and one is a broken drill-bit segment. The landing-gear forging is shown in Figure 1. The landing-gear forging is aluminum and contains large pockets (1½" deep x 1" wide x 16" long). The minimum radius is ¼" (there are no holes, except flaw holes) but the component has both doubly curved and tapered surfaces. The surface finish is 100-300 inches (r.m.s.).

3.2 Component II

A wing-attachment component for the F-16 (Part No. 81755 Assy. 16W165-21/SN F424172) that is similar in size and shape to the one shown in Figure 2 has been selected for use as component II. The surface is much smoother than component I, but the radii are as small as 1/8" in several places on the specimen. There are rather small pockets, especially designed to provide fastener hole entry, that are 1/4" deep and about 3/4" diameter.

3.3 Component III

Component III is an isothermal bulkhead machined to final shape from a plate of aluminum. The top and bottom view of this component is shown in Figure 3. Like other bulkheads, it has many pockets with radii of 1/8" to 1/2" between the webs. The flange thickness in the pockets vary from .09" to 3/8". There are several holes and cutouts in the pocket area. The maximum thickness of the bulkhead is 5.16". This part is especially suited for a test component because it has naturally occurring porosities which were induced during the forging and rolling processes and are located in the mid-plane of the plate thickness.



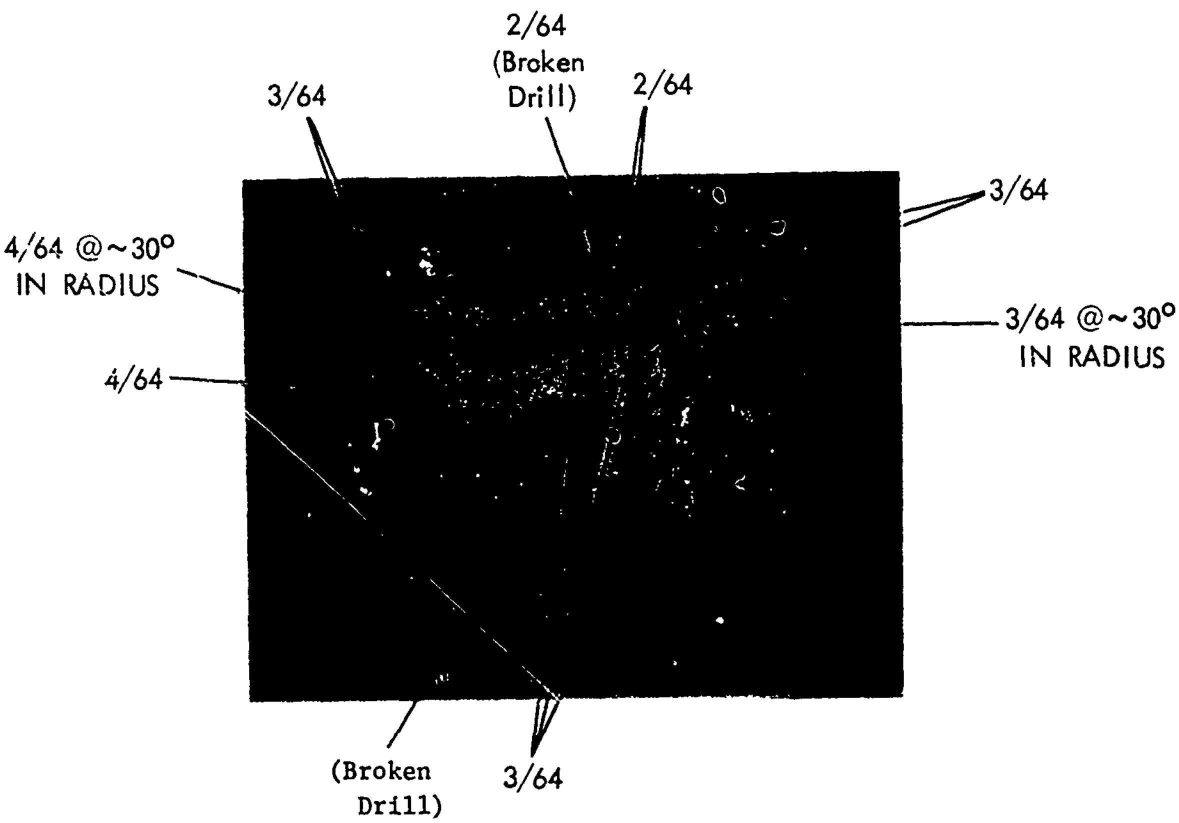


Figure 1. F-111 Landing Gear Forging

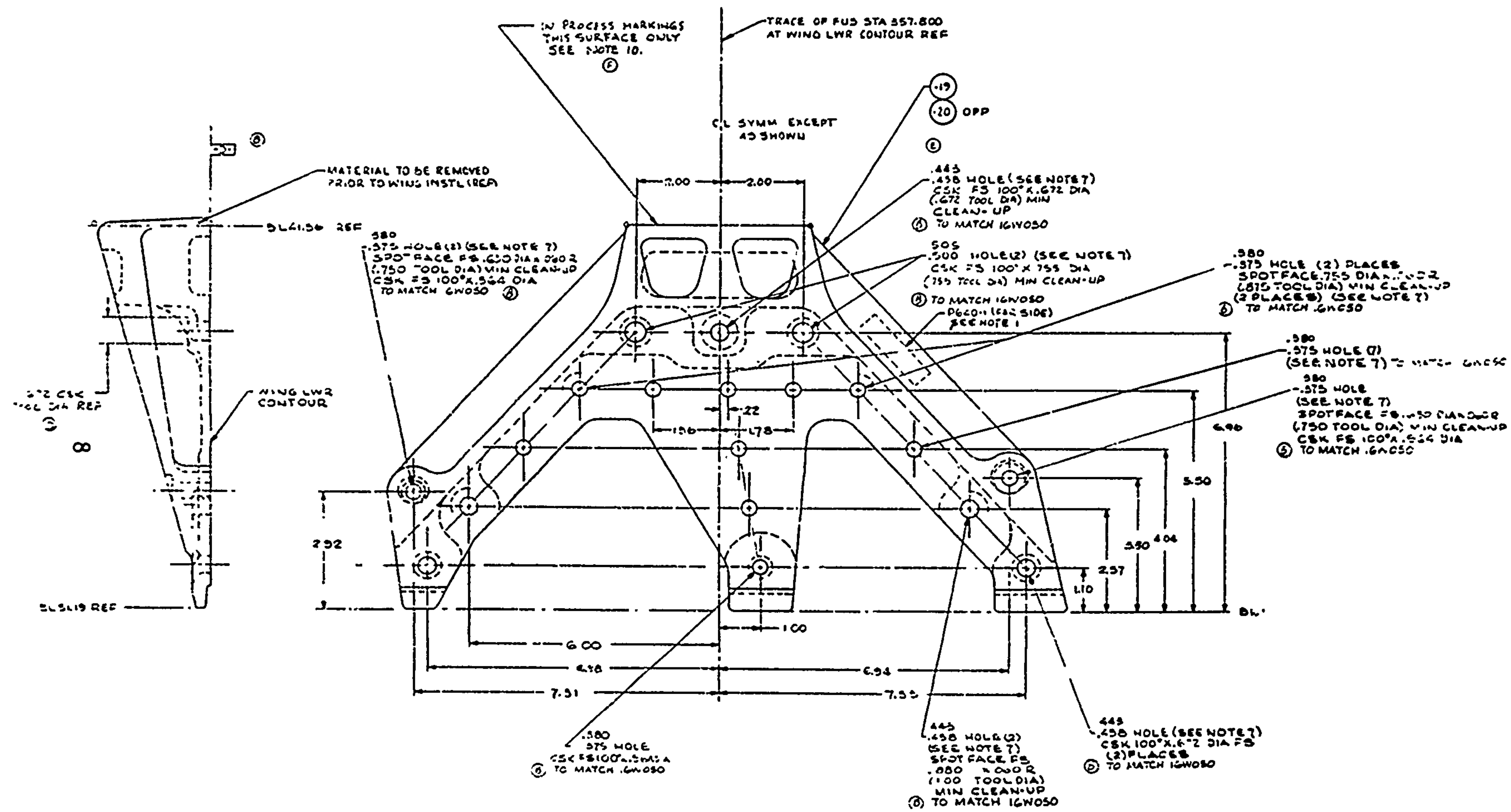


Figure 2 Engineering Drawing of the Wing Attachment Component for F16

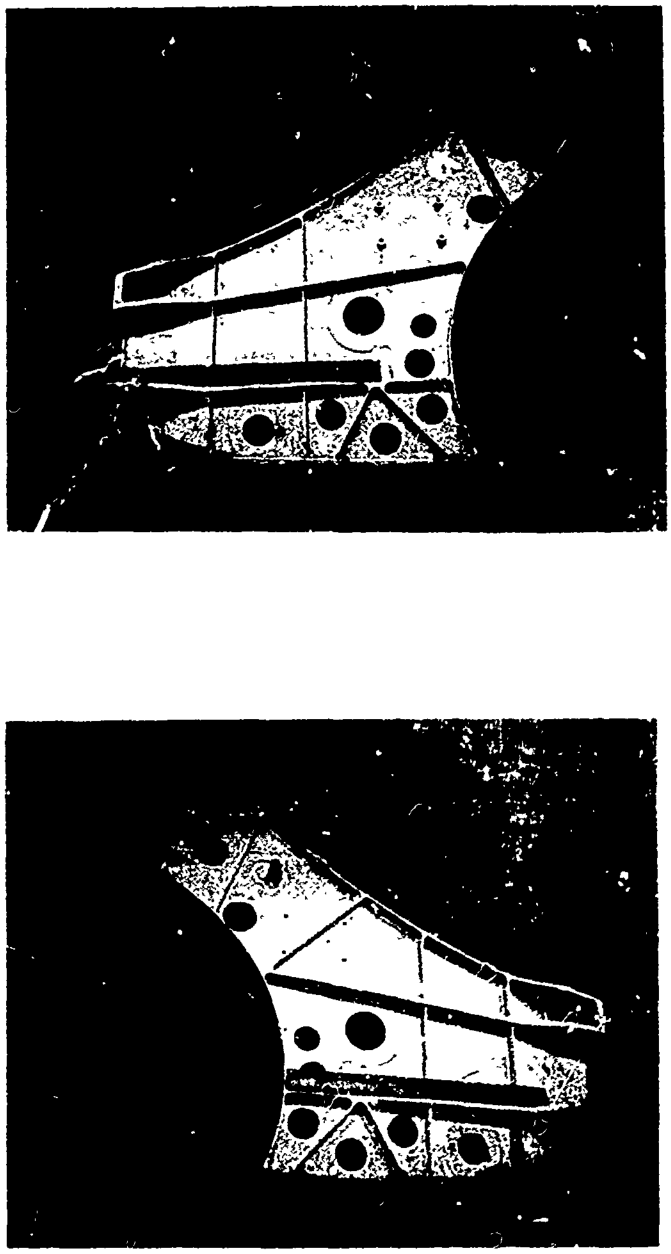


Figure 3. Photograph of Top and Bottom View of F-16 Isothermal Bulkhead

SECTION IV

THE COMPUTER-AUTOMATED ULTRASONIC-INSPECTION SYSTEM

The CAUIS, which was developed in a previous AFML contract (F33615-72-C-1828), was modified and optimized to achieve the objectives of this present contract. The optimized CAUIS is quite different from the system developed under the previous contract. The previous system was designed for contour following over simple-shaped aircraft structures from a constant distance of separation. The optimized system, on the other hand, is specially configured to implement the zone-scanning approach (will be discussed in detail in this report), which is best suited for inspecting components having complex near-net shapes such as those typified by the F-111 landing-gear forging or the F-16 isothermal bulkhead. The system utilizes primary standard ultrasonics and computer components, but some special interface items have been custom designed and built by General Dynamics to integrate the various components into an operating system.

The optimized CAUIS as with the CAUIS is comprised of essentially five subsystems: the ultrasonic and its associated electronics instrumentation, the five axes scanner-immersion tank and the scanner control instrumentation, the PDP 11/45 computer and its associated periphery equipment, the Tektronix display and hard copying unit, and the digitizing instrumentation. A picture of the CAUIS is shown in Figure 4. What is not shown in this picture is the second ultrasonic instrument that was designed and built to implement the Zone Scanning and a transient digitizer made by Inter-Computer Electronic, Inc. All these subsystems and the capabilities of the optimized CAUIS will be discussed in the following subsections of this report. A detailed discussion of the system's operation is given in Appendix B.

4.1 Ultrasonic Techniques and Instrumentation

The ultrasonic techniques and the two ultrasonic systems that were developed to achieve the objectives of the previous and the current AFML contract will be discussed in this subsection.

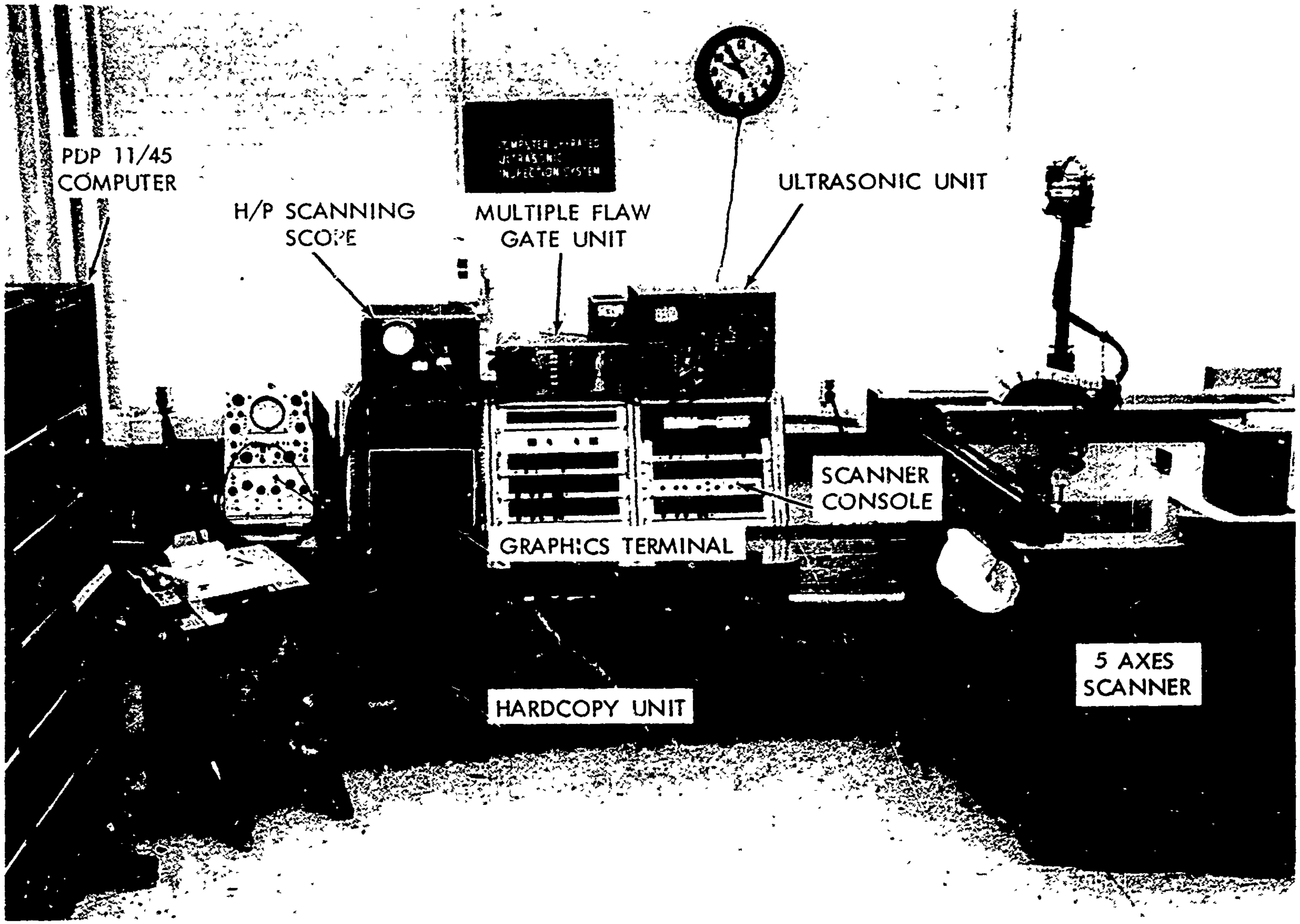


Figure 4. AFML Computer Automated Ultrasonic Inspection System

4.1.1 Ultrasonic Techniques for Inspection

The ultrasonic equipment for the CAUIS can operate in the reflected compressional and shear mode, in the through-transmission compressional mode, and in the pitch-catch compressional and shear mode. The frequency range for all these modes of operation is from 1 to 10 Mhz. In the compressional mode, the CAUIS is capable of inspecting forgings with curved-near and flat-far surfaces, curved-far and flat-near surfaces, curved-near and -far surfaces, radii from 0.75 inch and larger, holes in near surfaces, holes in far surfaces, and holes through the forging. Flat bottom holes with 3/64-inch diameter can be detected readily through six inches of aluminum. The CAUIS scans and indexes primarily in rectangular coordinates. However, it can scan and index in cyclindrical coordinates to inspect cyclindrical components such as engine disks. The CAUIS can also digitize ultrasonic signals to perform signal-processing routines such as ultrasonic spectroscopy by using a Tektronix scope as a delay and a HP scope with vertical output and horizontal-sweep input for digitization.

The ultrasonic equipment for the optimized CAUIS operates primarily in the reflected compressional and shear mode. The frequency range of operation is from 1 to 25 MHz. It can detect 3/64-inch-diameter FBH located 0.075 inch from the top surface through three inches of aluminum. This new ultrasonic equipment was designed and built for the Zone Scanning approach to inspect complex near-net-shape airframe components with 1/8-inch radii.

4.1.2 The UM 771 System

The ultrasonic instrument for the CAUIS was purchased and modified in 1973 and is an Automation Industries Type UM 771 reflectoscope. At that time, it was the most appropriate off-the-shelf instrument that could be purchased for modification to achieve the objectives of the previous AFML contract. The basic instrument consists of the following components:

1) UM 771 Display Chassis
2) Type AGIFM Timer Module
3) Pulser/Receiver Type 10S DB
4) Dual Type H Transigate
5) Special-Function Chassis
6) Distance-Amplitude-Compensation Unit (DAC)
7) Pulser Type 10S

A picture of this instrument is shown in Figure 5. In addition to these components of the basic instrument, many modifications and custom-designed and-built components were made to interface it with the computer.

A multiple-flaw gate circuit was added to detect and record the amplitude and depth from the top surface of two defects in the path of the sound beam.

An automatic-flaw gate-width circuit was designed and built to enable the computer to set and vary the gate width to accommodate thickness variations of the structure under inspection.

An automatic gain control was added to provide direct computer control of the gain by changing the DB settings of the programmable attenuator. This attenuator can be varied from zero to 99 DB in 1-DB steps. This automatic gain control enables the computer to automatically set the gain in the automatic calibration routine and monitor potential deteriation of the transducers and electronic circuits affecting the sensitivity of the system.

A more detailed discussion of this ultrasonic system and its capabilities can be found in the final report of the previous AFML contract (AFML-TR-75-82, May 1975).

4.1.3 Zone-Scanning Ultrasonics

The real-time zone-scan method of scanning complex geometry parts required a very large number of circuits modifications to the UM 771 ultrasonic instrument and computer interface. These modifications would make it difficult to change from the new method of operation to to the previous modes. In fact, the capabilities of the CAUIS, as discussed in the previous two subsections, would have to be destroyed in order to incorporate the new circuits so as to achieve the objectives of this present program. Because of this, the simplest approach was to design and build a complete new ultrasonic system dedicated to the zone-scan mode. The new unit is connected into the system simply by changing the transducer cable and computer interface cable from the previous ultrasonic unit to the zone-scan unit and changing two computer interface connectors. A separate oscilloscope is required to monitor signals from the new system. Although this new ultrasonic unit is designed and built by General Dynamics, Fort Worth Division, commercial systems can now be purchased to essentially perform the zone-scanning approach. However, because of cost and scheduling constraings, the decision was made to custom build the system.

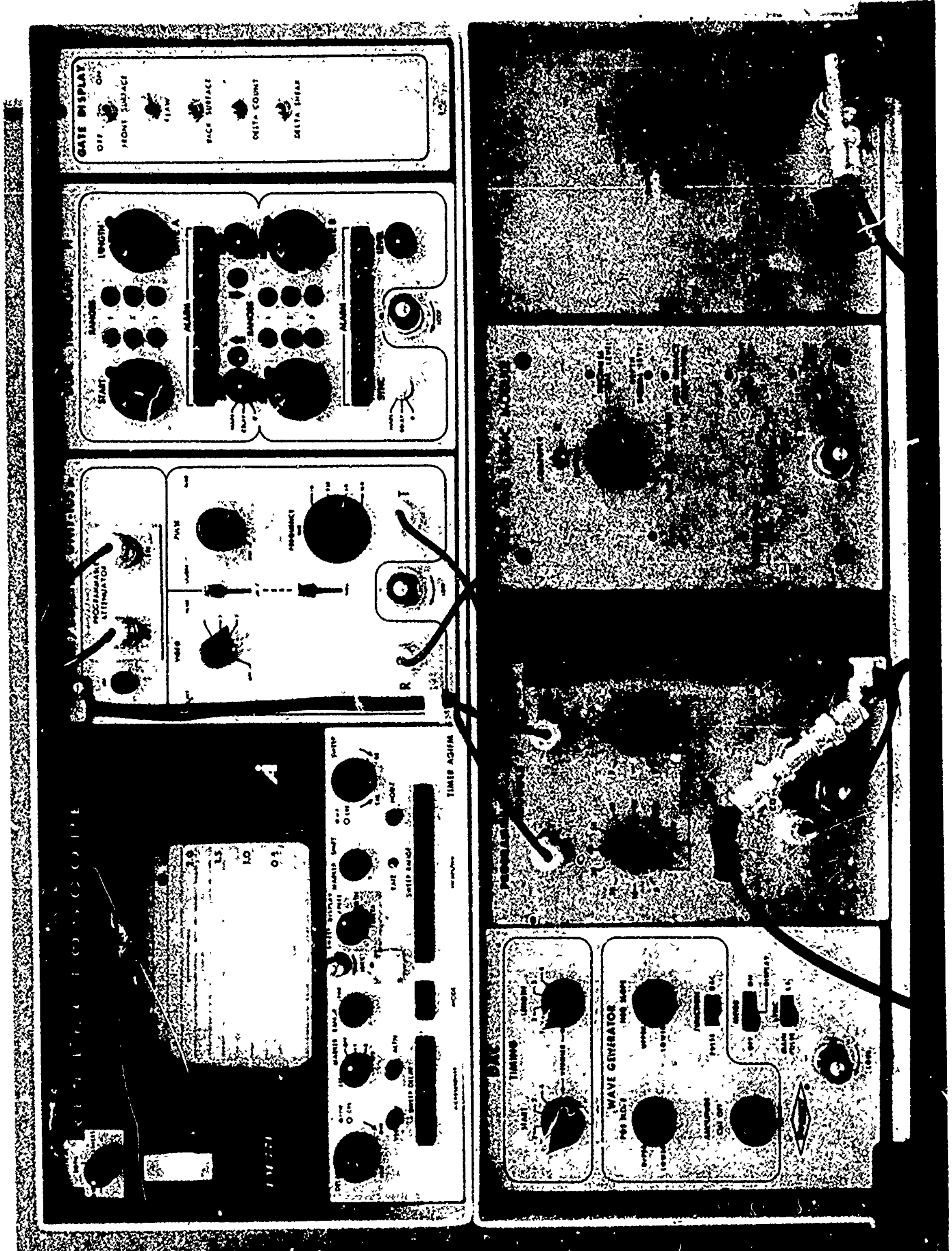


Figure 5. Ultrasonic Test Unit for Computer Automated System

Zone-Scan Mode: The zone-scan mode is basically a reflection mode of operation. The transducer is pulsed by the pulser and feeds echos to the receiver. The logic and timing circuits provide signals to the computer which allow the software to identify the echos as front-surface reflections, flaw reflections, back-surface reflections, or back-plate reflections. Flaw-amplitude, separation-distance, and flaw-depth and-thickness information are also supplied to the computer. Figure 6 is a photograph of the ultrasonic package and Figure 7 is a photograph of the gate and logic module showing plug-in circuit boards. A signal timing diagram is shown in Figure 8. The ultrasonic unit consists of the following components.

- Pulser
- Ultrasonic Receiver
- Timing Logic Circuit
- Multichannel Amplitude-Comparator Bank

Pulser: The pulser-circuit schematic is shown in Figure 9. The circuit is built on a circuit board that is housed in a Nuclear Instrument Module (NIM) double-width unit, which also contains the receiver. The pulse-generating element is a metrotek Inc. Type P-105A. It receives +300 volts from a voltage doubler/tripler rectifier. By moving the 10K, 1-watt resistor from Terminals 3 and 4 to 1 and 2, +450 volts can be applied to the pulser. Triggering of the pulser is normally from the external pulser sync from the timing logic circuit. Variable damping is provided by a front panel screwdriver adjustment. Interconnection wiring of the pulser circuit is shown in Figure 10.

Ultrasonic Receiver: The ultrasonic receiver circuit is mounted on one circuit board and shown schematically in Figure 11. It consists of a field-effect transistor preamp, gain-control potentiometer, wide-band-pulse amplifier with emitter/follower output, and full-wave detector with reject control. The detector output provides 0 to +10-volt video pulses, which are required for the high dynamic range of the amplitude comparators. The receiver circuit board is mounted in the double width NIM plug in unit with the pulser circuit. Interconnection wiring to the panel controls and external circuits is shown in Figure 12.

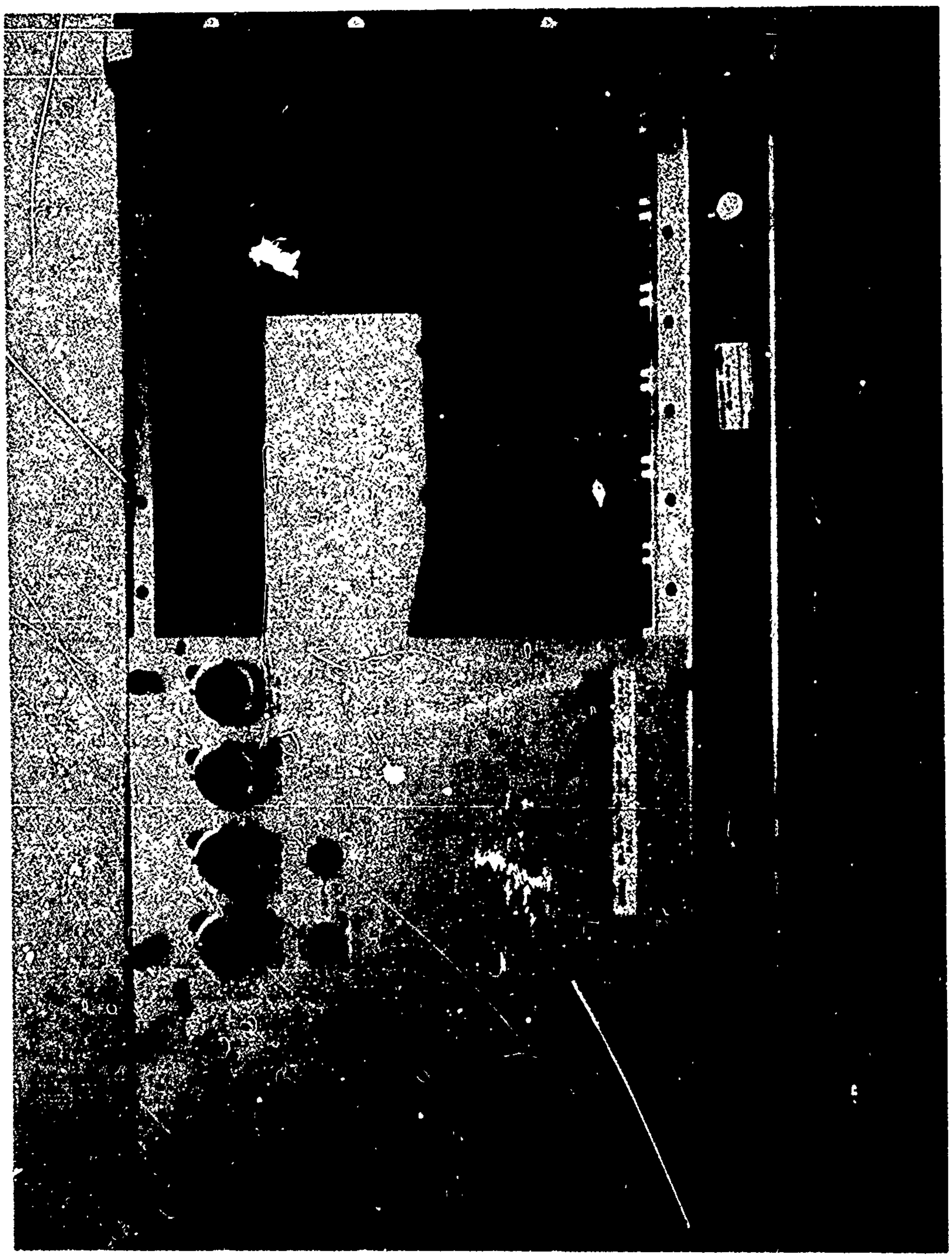


FIGURE 6. Ultrasonic Test Unit for Zone Scanning

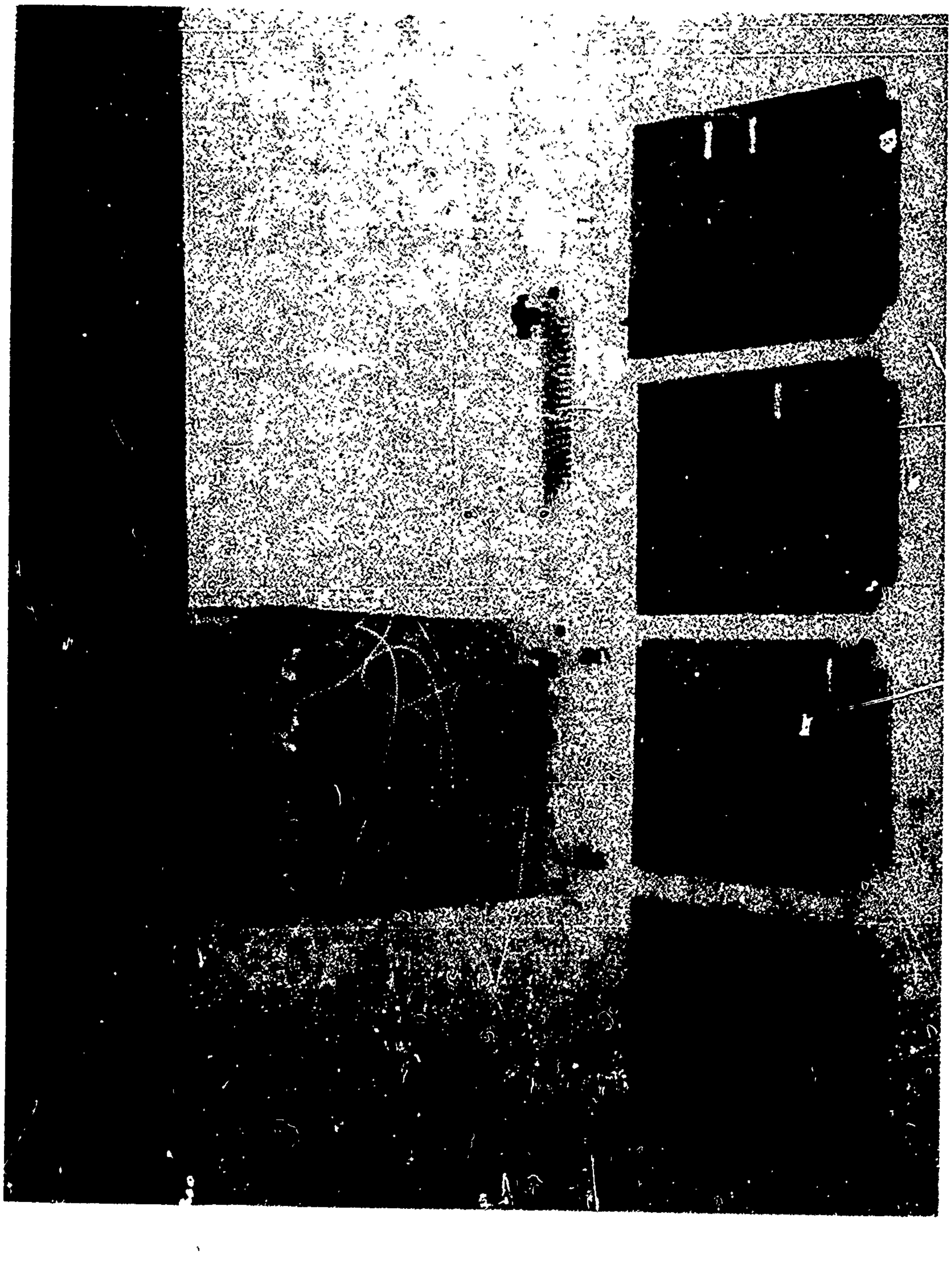


FIGURE 7. Gate and Logic Module Showing Plug-In Circuit Boards

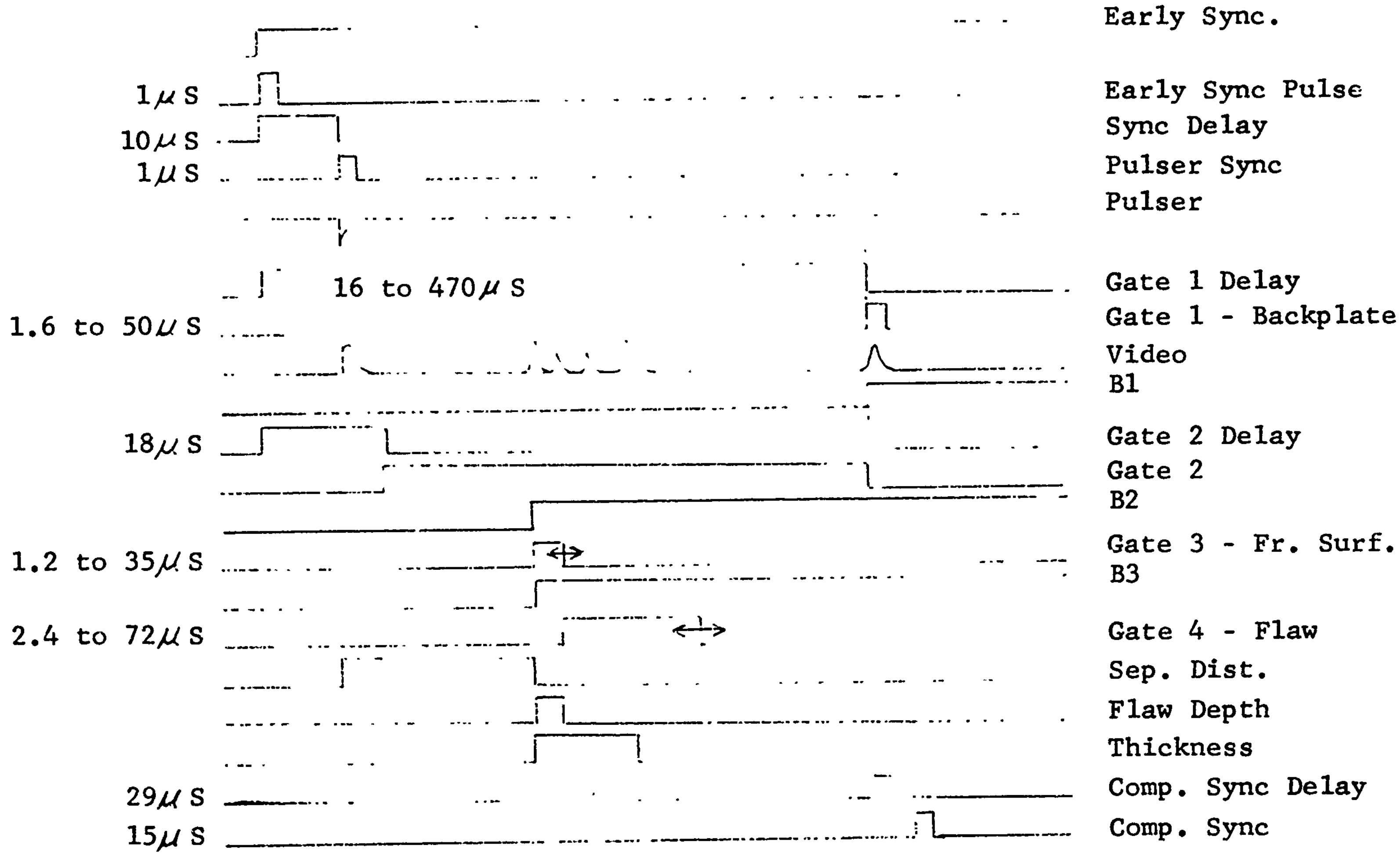


FIGURE 8. Timing Gates For Real Time Ultrasonic Processing

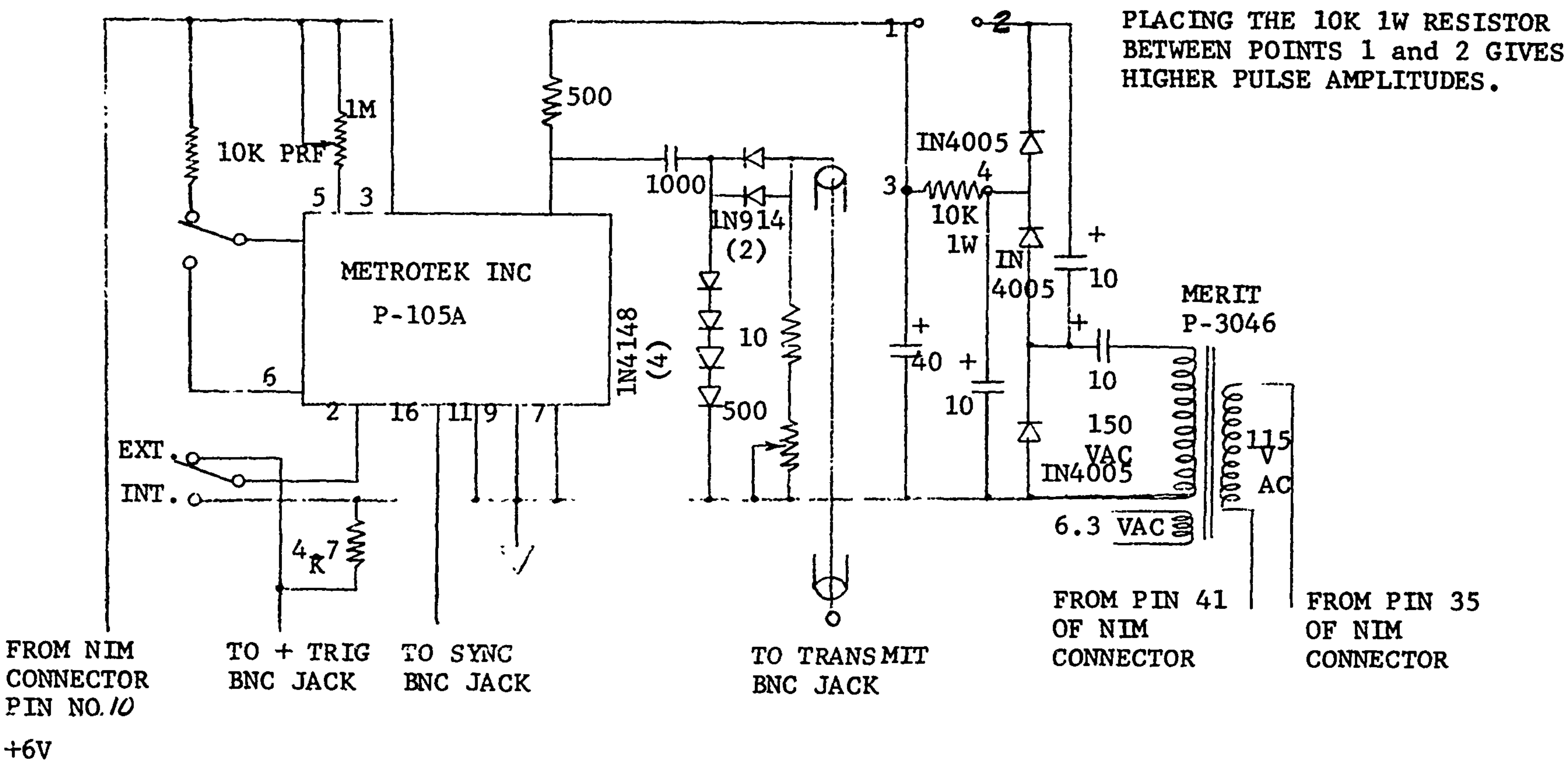


FIGURE 9. Pulser Circuit Board Schematic

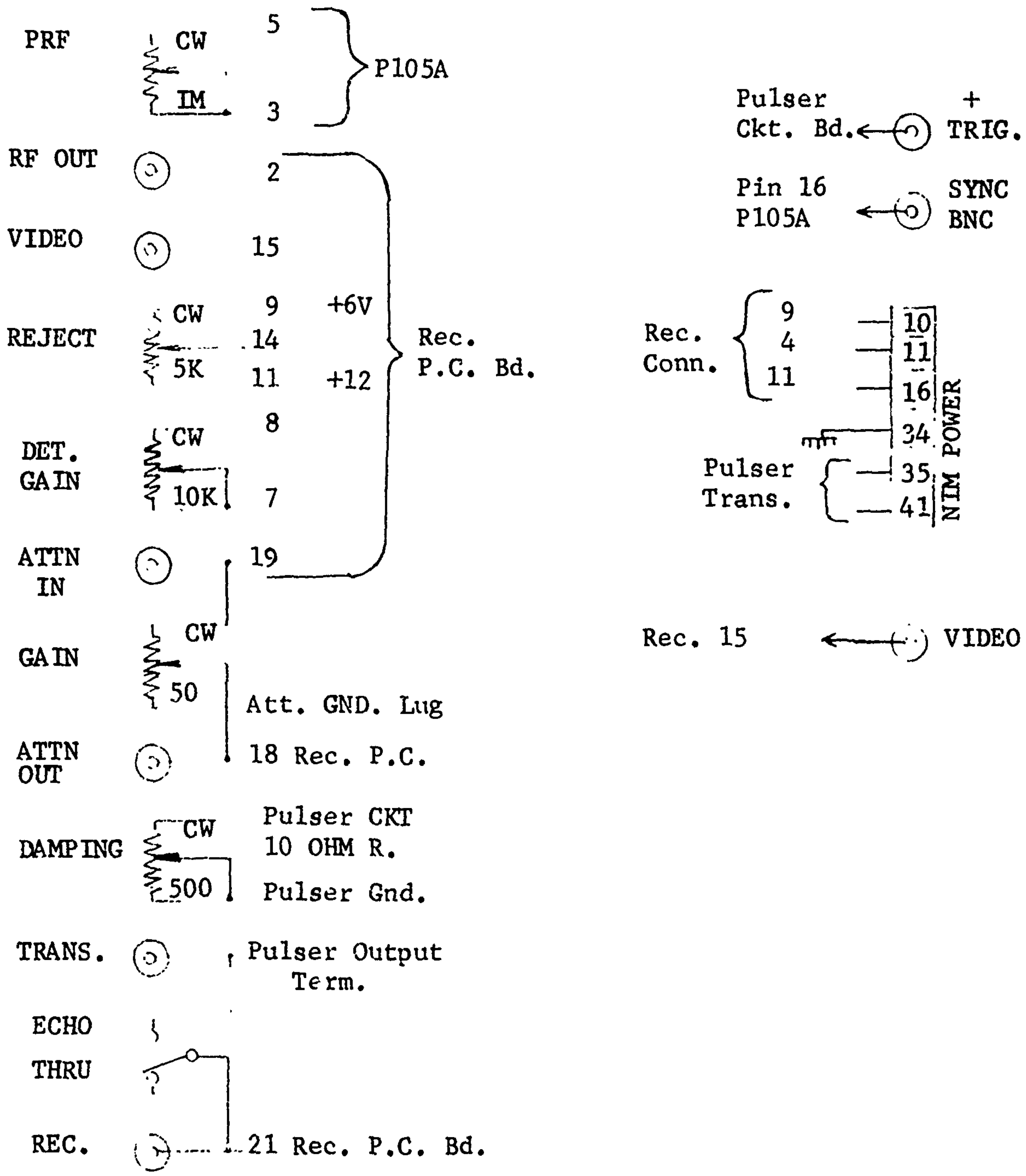


FIGURE 10
Pulser/Receiver Chassis and Panel Wiring Schematic

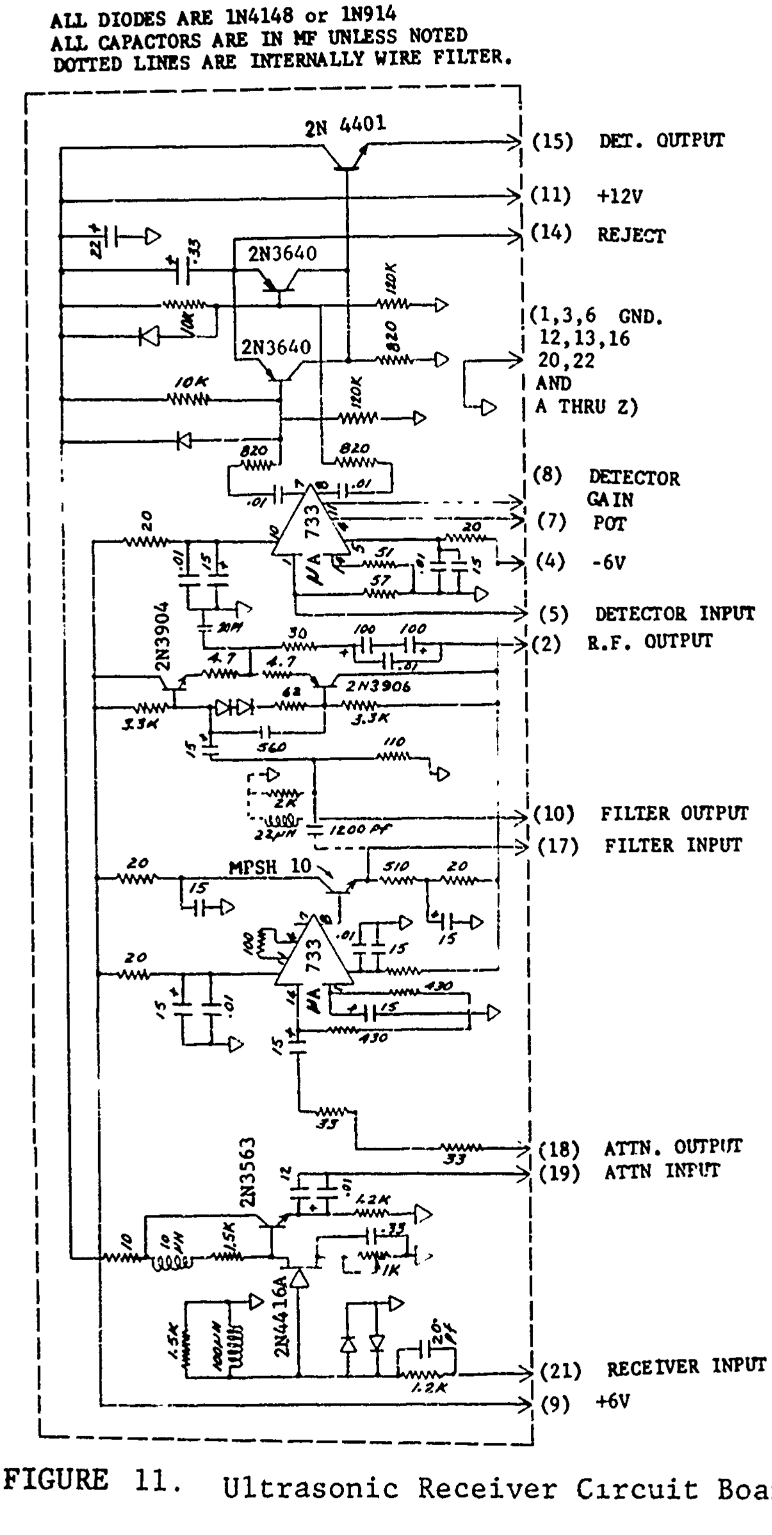
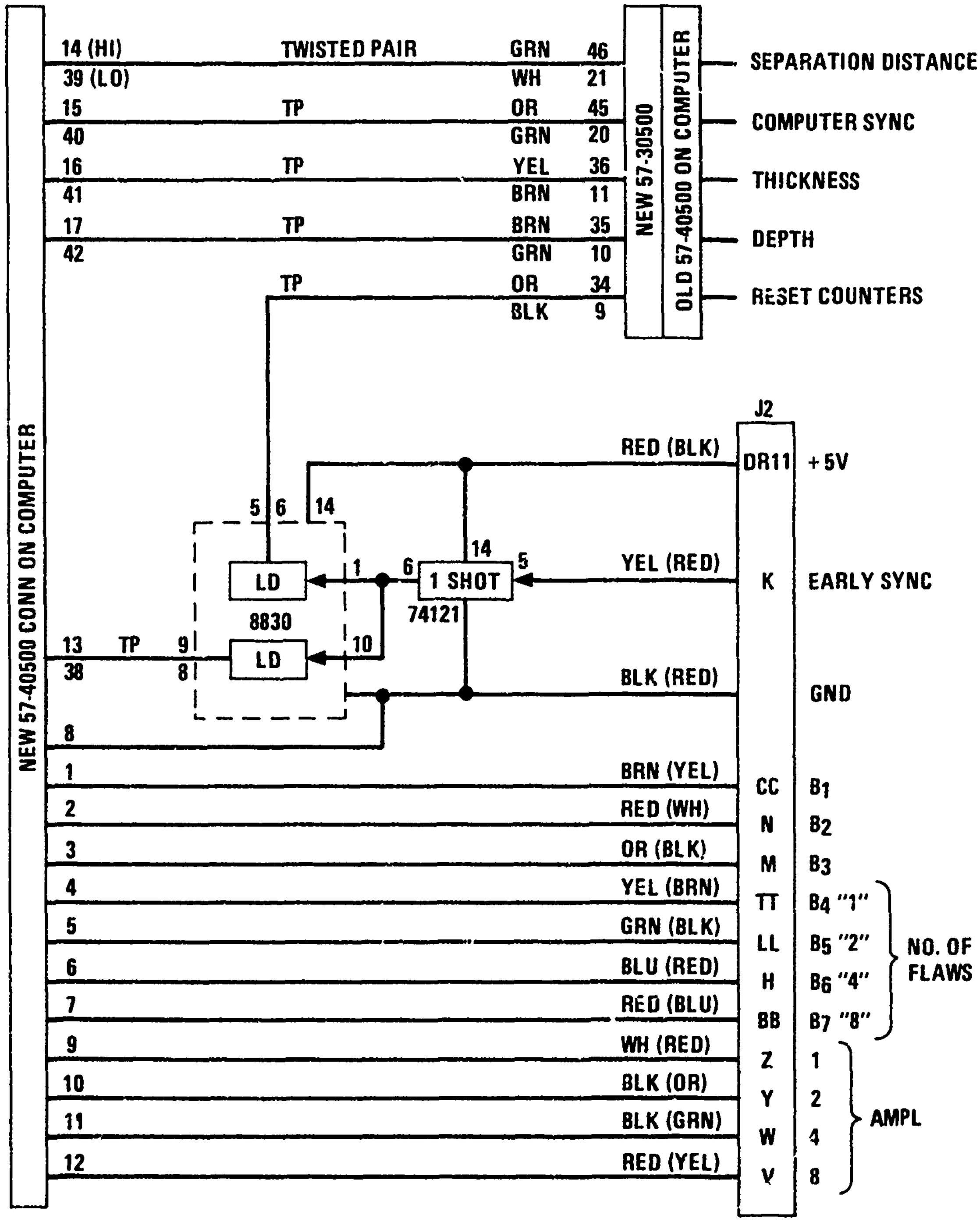


FIGURE 11. Ultrasonic Receiver Circuit Board Schematic



NOTE: 1. BLK (RED) MEANS THE BLACK WIRE OF A BLACK–RED TWISTED PAIR
2. THE DUAL LINE DRIVER AND 1 SHOT MV ARE ON CIRCUIT BOARD

FIGURE 12. Wiring Diagram of the Computer Interface Cable

Timing Logic Circuit: The timing logic circuits are on one circuit board, which plugs into a slot in a quad-width NIM plug-in unit. The circuit schematic is shown in Figure 13. Explanation of operation of these circuits will refer to this figure and the timing diagram, Figure 8. IC5B is a line receiver which receives an early sync pulse from the computer. With the PRF switch in "computer" mode, this early sync signal triggers multivibrator (MV) IC1A to generate a RESET pulse and trigger pulser delay MV IC1B. IC1B output triggers pulser sync MV IC2A after a 10-microsecond delay. IC2A output is fed to the pulser trigger in put to initiate a pulse to the transducer. It also sets the separation-distance latch IC 14B. The reset pulse from IC2A resets all counters and latches and triggers the GATE 1 DELAY MV IC6A and GATE 2 DELAY MV IC11A. GATE 1 MV IC6B is triggered by the trailing edge of IC6A, which occurs at a time set in by the GATE 1 delay dial on the front panel. It is set to coincide with an echo pulse from the back plate. GATE 1 MV width is set by the front panel control to be wide enough to include the back plate echo when its distance from the transducer varies slightly. Computer sync delay MV IC7A is triggered by the leading edge of GATE 1 and provides a fixed delay of 30 microseconds before it triggers COMPUTER SYNC MV IC7B. IC7B generates a 15-microsecond pulse, which is fed through line driver IC10A to signal the computer that ultrasonic data from one transmitted pulse is ready. GATE 2 DELAY MV IC11A provides a fixed delay of approximately 20 microseconds before triggering GATE 2 MV IC11B. IC11B is reset by the leading edge of GATE 1. GATE 2 and the output from Comparator A_1 are fed to AND GATE IC8A, and the first echo above Comparator A_1 level will set flip-flop (FF) IC9C. Output of IC9C provides a bit (B2) to the computer designating a reflection from something closer than the back plate. It also triggers front surface GATE 3 MV IC12A. GATE 3 width is variable from 1.5 to 35 microseconds by front panel control. Its trailing edge starts flaw GATE 4 MV IC12B, whose width is variable from 2.4 to 72 microseconds by front panel control. Gate 3 and the output of Comparator A15 are fed to AND GATE IC8B. If the pulse coincident with GATE 3 was large enough to give an output from Comparator A15, IC8B output will set Latch IC9A. This will feed a bit (B_3) through Buffer IC3C to the computer designating that the first echo was as large as A_{15} level and represents a front surface. Flaw GATE 4 is fed to AND gates in the flaw amplitude latch circuits and to AND GATES IC3B and IC3D. IC3B feeds NOR GATE IC13B and, if its second input from A_{15} occurs during the flaw gate, thickness Latch IC14D will be cleared. IC14D has been previously set by the front surface signal from GATE 3. Output

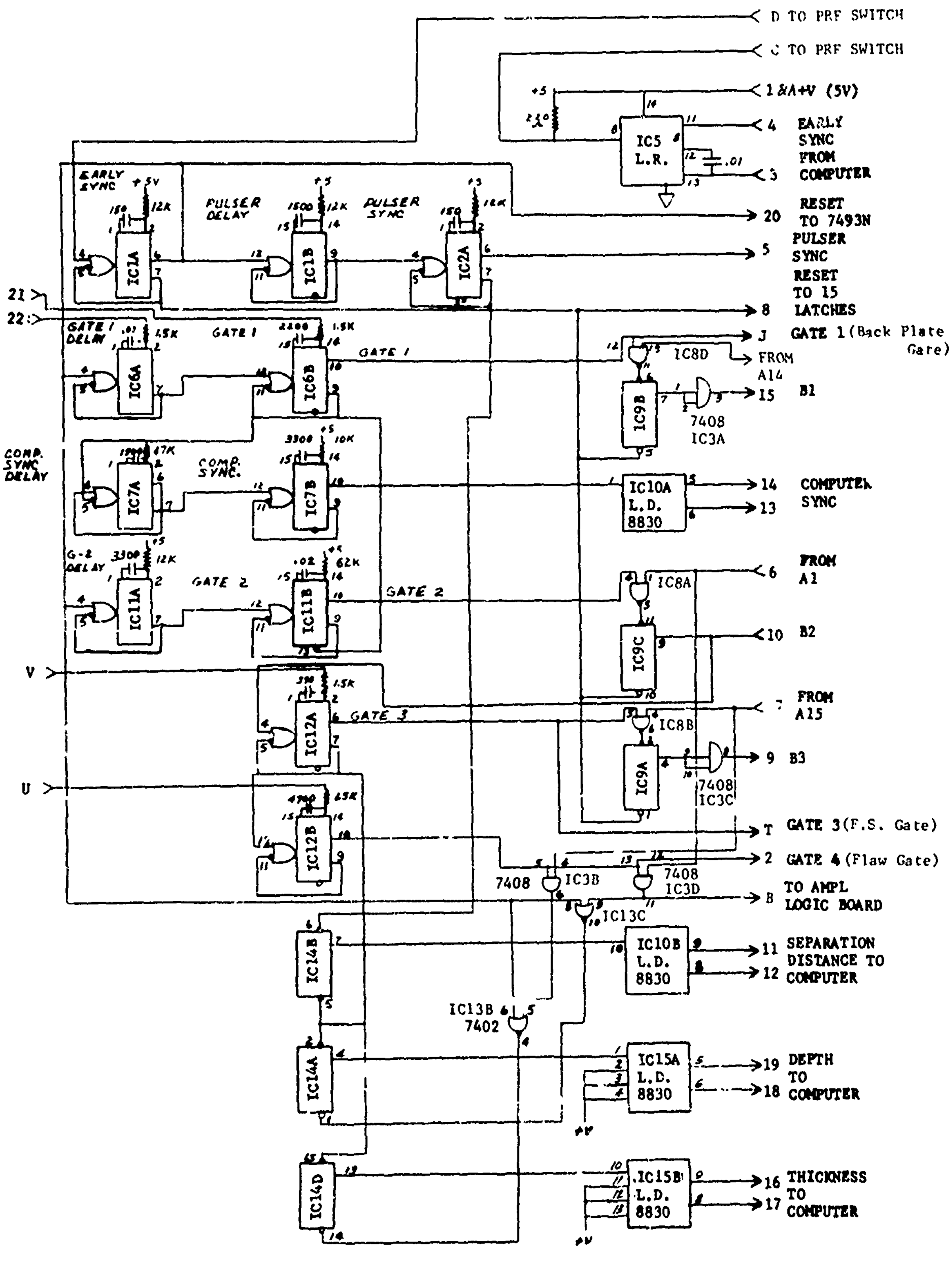


FIGURE 13. Timing Logic Circuit Schematic

of IC14D is a positive signal whose width is proportional to thickness. It is fed to the thickness counter in the computer through line driver IC15B. IC3D feeds a signal to the amplitude logic circuit board and to NOR gate IC3C and if its second input from A_1 occurs during the flaw gate, depth latch IC14A will be cleared. IC14A had been previously set by the front surface signal from GATE 3. Output of IC14A is a positive signal whose width is proportional to flaw depth. It is fed to the depth counte in the computer through line driver IC15A. Separation distance latch IC14B, which was set by the pulser sync MV, is cleared by the front surface signal from GATE 3. Output of IC14B is a positive signal whose width is proportional to separation distance. It is fed to the separation distance counter in the computer through line dirver IC10B. IC8D is a NAND gate, which sets latch IC9B when a signal from comparator A_{15} coincides with GATE 1. Output of IC9B feeds a bit (B_1) through buffer gate IC3A to the computer to indicate that there is not a part between the transducer and the backplate.

Multichannel Amplitude Comparator Banks: A set of 15 level comparators are logarithmically biased to provide means for measuring the amplitude of the first flaw signal in real time and transferring its amplitude to the PDP 11-45 computer as a four-bit binary number. This is accomplished by three circuit boards in the quad NIM module. Figure 14 shows the 15 level comparators and Figure 15 shows the flaw amplitude latch circuit board and the flaw amplitude logic circuit board. The logarithmically related bias voltage values are shown on the schematic. The 5-volt and 3.3-volt bias represent 10 volts and 6.6 volts respectively because the intput signal to this comparator is reduced by a factor of two by the input resistance divider. Signals over 5 volts to the other 13 comparators are limited by the 470-ohm resistor and biased diode. The 15 comparators cover an amplitude range of almost 3 decades. Each comparator produces a TTL logic level pulse for all video pulses above its bias level. These pulses are fed to the NAND gates in the flaw amplitude latch circuit. The pulses that are coincident with the flaw gate cause the NAND gate outputs to set their respective bi-stable latch. The pulses from comparator A_1 are also fed to the timing logic circuit board and to the four-stage binary counter. This counter feeds four bits to the computer to indicate the number of signals in the flaw gate. This counter also inhibits the latch NAND gates after one flaw signal is analyzed. This is done with the 4-input NAND gate (7425). Each amplitude latch whose bias level is below the signal level is set to the "one" state and held there until the next early sync. These "ones" are sent to the flaw-amplitude logic circuit exclusive "OR" gates (7486). These "OR" gates inhibit the outputs of all except the highest comparator

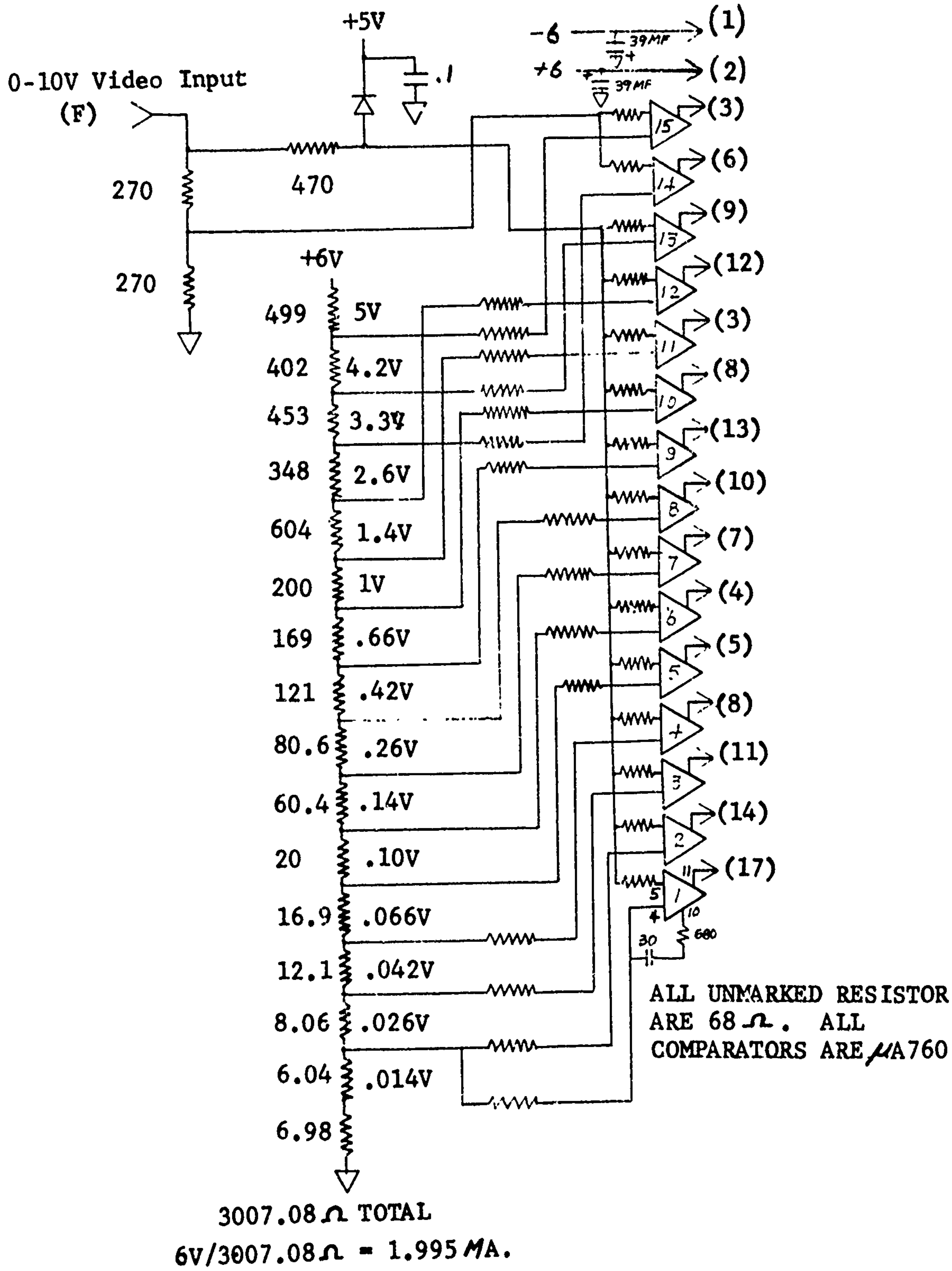


FIGURE 14. Multichannel Amplitude Comparator Bank

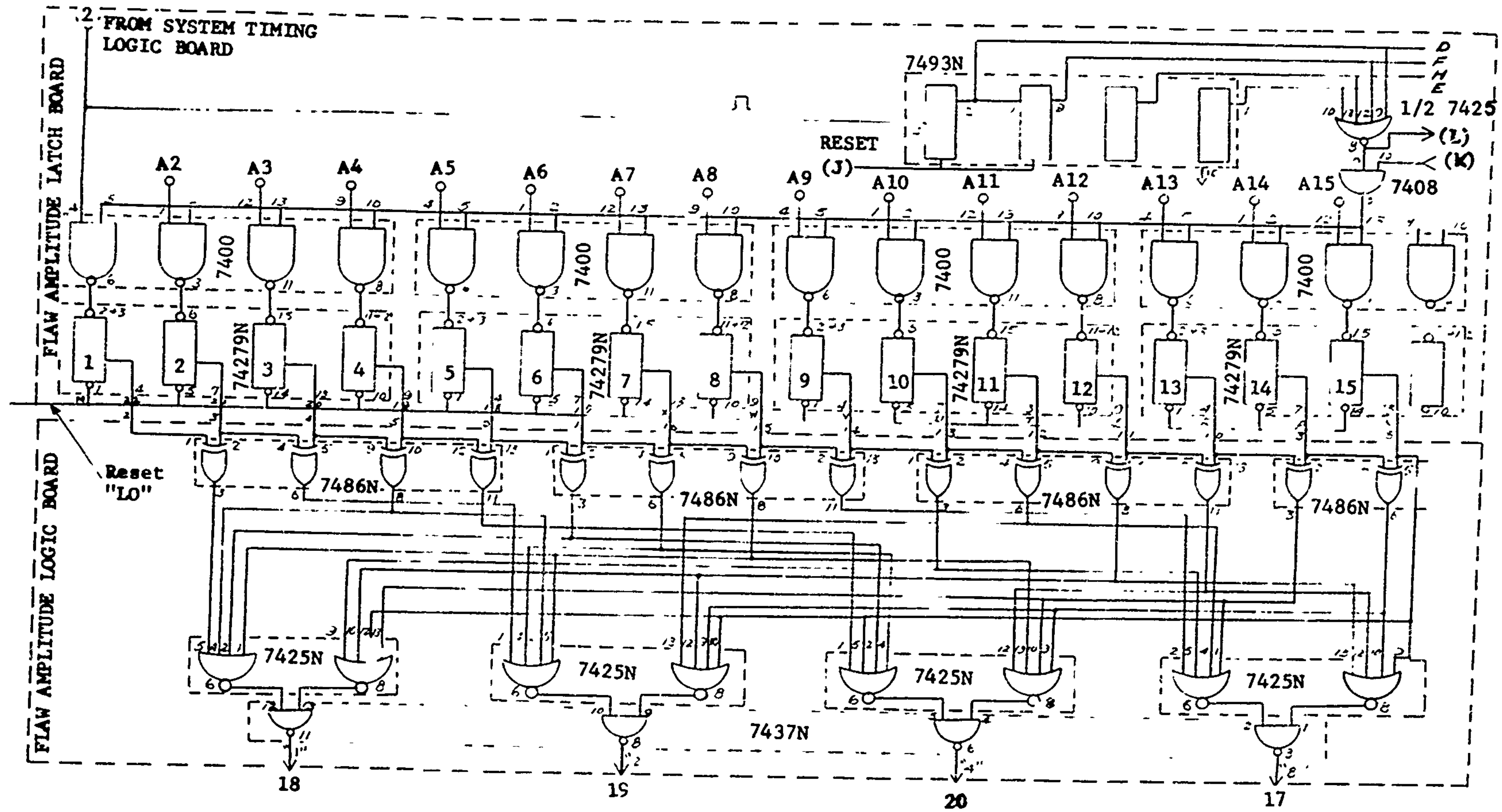


FIGURE 15. Flaw Amplitude Latch and Logic Circuit Boards

triggered. Lines 1 through 15 from the "OR" gates represent their respective bias level. They are fed to the 4-input NOR gates (7425N) and 2-input NAND gates (7437N) to convert the 1 through 15 lines to four lines of binary data to indicate the amplitude number. The 7437N are NAND buffers which can drive the computer data lines without line drivers.

Interconnection of the circuit boards and front and rear panel of the quad NIM module are shown in Tables 1, 2, and 3 and Figure 16.

Figure 16 also includes a schematic of a wide-band amplifier used to feed display signals to a monitoring oscilloscope. The oscilloscope is externally triggered by "TEEing" on to the early-sync output jack. The video signal, GATE 1, GATE 3, and GATE 4 can be switched into the amplifier individually or collectively with four front panel toggle switches.

Figure 17 is a schematic of the LOCAL PRF generator. It can be switched in to provide early sync without the computer sending it. It is mounted on a fifth circuit board in the quad NIM module.

TABLE 1. INTERCONNECTION OF THE CIRCUIT BOARDS

J1 TIMING LOGIC CIRCUIT BOARD

A	J2-1, J2-A, FR. PANEL POTS
B	J3-2
C	↑
D	
E	GND
F	
H	↓
J	TO DISPLAY SWITCH
K	TO J3-15 (A14)
L	↑
M	
N	GND
P	
R	
S	
T	↓
U	GATE 4 WIDTH CONTR. POT.
V	GATE 3 WIDTH CONTR. POT.
W	↑
X	GND
Y	
Z	↓
1	J2-1, J2-A, J1-A,FR.PANEL POTS
2	J3-K
3	REAR CONN. PIN-38
4	REAR CONN PIN-13 (COAXIAL CABLE)
5	TO PULSER SYNC JACK (BNC)
6	J4-14
7	J4-3 to J3-16
8	J3-M
9	REAR CONN PIN 3
10	REAR CONN PIN 2
11	REAR CONN PIN 14
12	REAR CONN PIN 39
13	REAR CONN PIN 40
14	REAR CONN PIN 15
15	REAR CONN PIN 1
16	REAR CONN PIN 16
17	REAR CONN PIN 41
18	REAR CONN PIN 42
19	REAR CONN PIN 17
20	J3-J
21	GATE 1 WIDTH CONTROL
22	GATE 1 DELAY CONTROL

J2 ARMPLITUDE LOGIC CIRCUIT BOARD

A	J3-A, J3-1, J2-1, J1-1, J1-A	
B	↑	
C		
D		
E		
F		
H		
J		
K		
L		
M	GND	
N		
P		
R		
S		
T		
U		
V		
W		
X		
Y		
Z	↓	
1	J2-A, J3-A, J3-1, J1-A, J1-1	
2	J3-22	(A_1)
3	J3-21	A_2
4	J3-20	A_3
5	J3-19	A_4
6	J3-18	A_5
7	J3-17	A_6
8	J3-N	A_{15}
9	J3-P	A_{14}
10	J3-R	A_{13}
11	J3-S	A_{12}
12	J3-T	A_{11}
13	J3-U	A_{10}
14	J3-V	A_9
15	J3-W	A_8
16	J3-X	A_7
17	REAR CONN -12 "8" AMPL.	
18	REAR CONN - 9 "1" AMPL.	
19	REAR CONN -10 "2" AMPL.	
20	REAR CONN -11 "4" AMPL.	
21	NC	
22	NC	

TABLE 2. INTERCONNECTION OF THE CIRCUIT BOARDS

J6 COMPUTER INTERFACE CONNECTOR (AMPHENOL)

1	J1-15	B_1	BACK PLATE IN GATE AND A_{15}		26		
2	J1-10	B_2	GATE 2 and A_1		27		
3	J1-9	B_3	FRONT SURFACE AND A_{15}		28		
4	J3-D	B_4	"1" ↑		29		
5	J3-F	B_5	"2" NO. OF		30		
6	J3-H	B_6	"4" FLAWS		31		
7	J3-E	B_7	"8" ↓		32		
8					33		
9	J2-18		"1" AMPL.		34		
10	J2-19		"2" AMPL.		35		
11	J2-20		"4" AMPL.		36		
12	J2-17		"8" AMPL.		37		
13	J1-4 (HI)		EARLY SYNC	RED	38	J1-3 (LO)	BLK
14	J1-11 (HI)		SEPARATION DIST.	OR	39	J1-12 (LO)	BLK
15	J1-14 (HI)		COMPUTER SYNC	OR/WH	40	J1-13 (LO)	BLK
16	J1-16 (HI)		THICKNESS	BLU	41	J1-17 (LO)	BLK
17	J1-19 (HI)		DEPTH	VIO	42	J1-18 (LO)	BLK
18					43		
19					44		
20					45		
21					46		
22					47		
23					48		
24					49		
25					50		

TABLE 3. INTERCONNECTION OF THE CIRCUIT BOARDS

J3 AMPLITUDE LATCHES CIRCUIT BOARD

A	+5V, J3-1, J4-22, J2-A, J2-1		
B	GND		
C	GND		
D	REAR CONN. -4	B_4 "1"	
E	REAR CONN. -7	B_7 "8"	NO.
F	REAR CONN. -5	B_5 "2"	OF
H	REAR CONN. -6	B_6 "4"	FLAWS
J	J1-20	(7493 RESET)	
K	J1-2		
L	NC	7425 OUTPUT	
M	J1-8	RESET LATCHES	
N	J2-8	15	
P	J2-9	14	
R	J2-10	13	
S	J2-11	12	
T	J2-12	11	
U	J2-13	10	
V	J2-14	9	
W	J2-15	8	
X	J2-16	7	
Y	GND		
Z	GND		
1	J3-A, J4-22, J2-A, J2-1,+5V		
2	J1-B	(A_1 + GATE 4)	
3	J3-2	A_2	
4	J4-11	A_3	
5	J4-8	A_4	
6	J4-5	A_5	
7	J4-4	A_6	
8	J4-7	A_7	
9	J4-10	A_8	
10	J4-13	A_9	
11	J4-16	A_{10}	
12	J4-15	A_{11}	
13	J4-12	A_{12}	
14	J4-9	A_{13}	
15	J4-6	A_{14}	
16	J4-3	A_{15}	
17	J2-7	6	
18	J2-6	5	
19	J2-5	4	
20	J2-4	3	
21	J2-3	2	
22	J2-2	1	

J4 COMPARATOR CIRCUIT BOARD

A		
B		
C	GND	
D		
E		
F	VIDEO INPUT JACK (BNC) (COAXIAL CABLE)	
H		
J		
K		
L		
M		
N		
P		
R	GND	
S		
T		
U		
V		
W		
X		
Y		
Z		
1	NIM CONN. - (-6V) PIN 11	
2	NIM CONN. - (+6V) PIN 10	
3	J3-16 & J1-7	(A_{15})
4	J3-7	(A_6)
5	J3-6	(A_5)
6	J3-15	(A_{14})
7	J3-8	(A_7)
8	J3-5	(A_4)
9	J3-14	(A_{13})
10	J3-9	(A_8)
11	J3-4	(A_3)
12	J3-13	(A_{12})
13	J3-10	(A_9)
14	J3-3	(A_2)
15	J3-12	(A_{11})
16	J3-11	(A_{10})
17	J1-6	(A_1)
18	NC	
19	NC	
20	NC	
21	NC	
22	J3-A, J3-1 (+5V)	

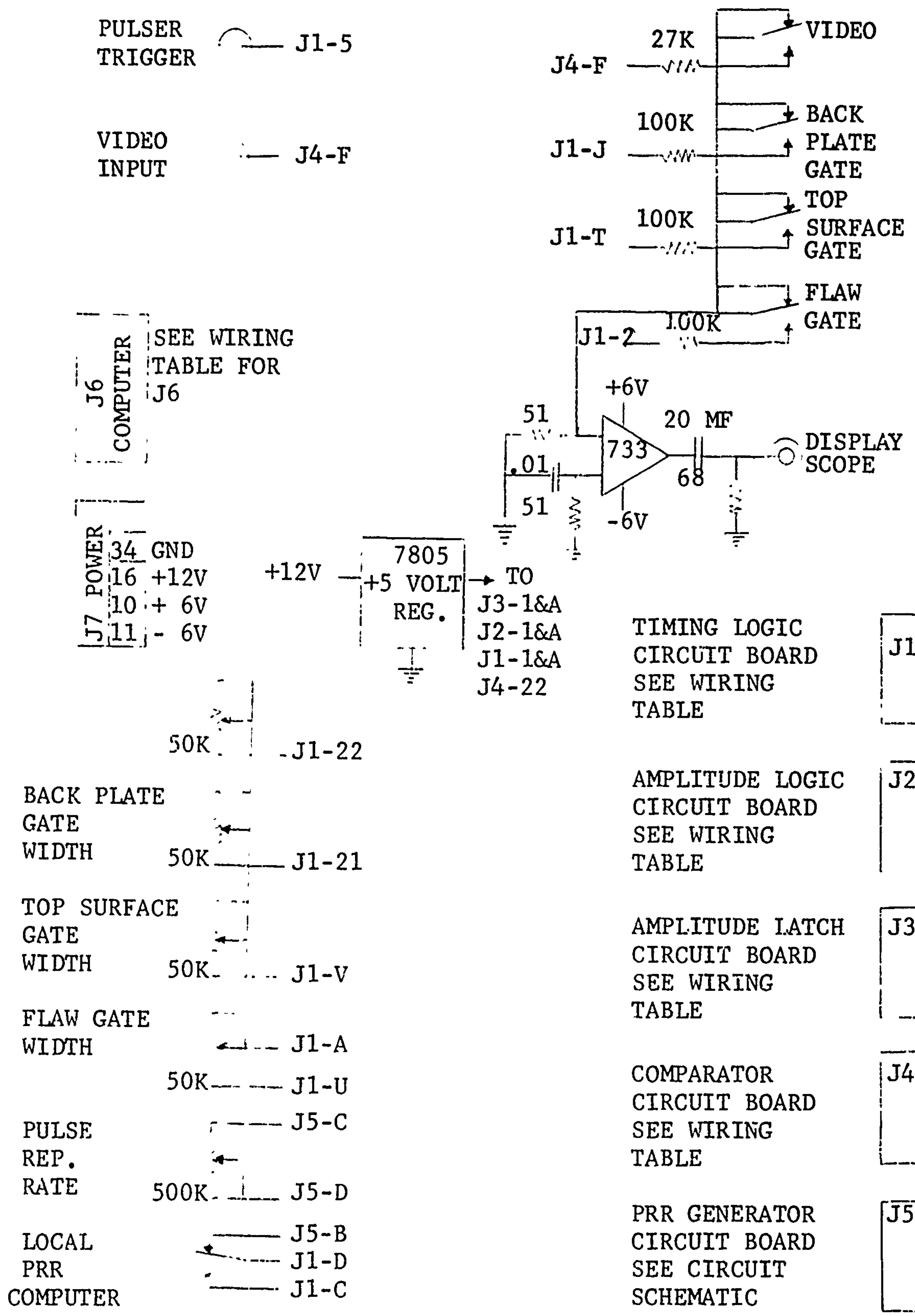


FIGURE 16. Logic and Amplitude Module Wiring Diagram

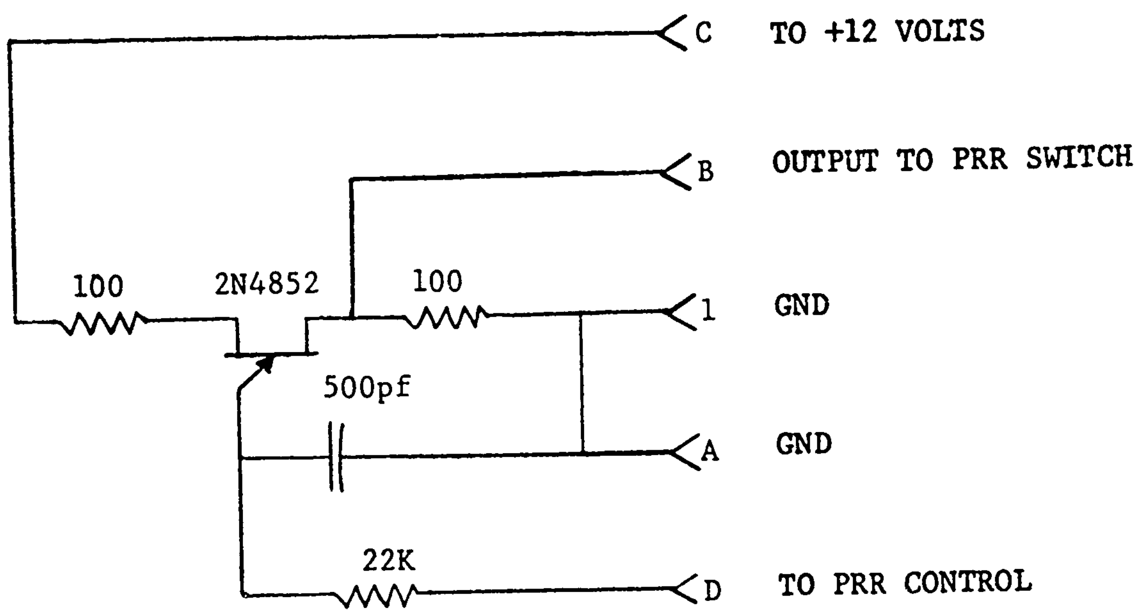


FIGURE 17. Local Pulse Repetition Rate Generator

4.2 Scanning System Development

The computer controlled five-axes scanning system and immersion tank were actually designed and built in the previous AFML contract (F33615-72-C-1828). However, there were two mechanical and one software development/improvement made as part of this contract. One mechanical improvement made was to the transducer holder assembly to provide a more accurate control and monitoring of the transducer directions (rotation and tilt). The second mechanical improvement made was to the scan speed in the X-direction. The software improvement made was to enable the scanner to scan in any vector direction in the X-Y plane. For completeness, the description and function of each subcomponent of the scanning system are discussed in the following subsections.

4.2.1 Test Tank

The test tank has an inside width of 4 feet, length of 6 feet, and depth of 3 feet. The tank has one 1-foot by 1-foot window installed in the front for visual inspection inside the tank. The tank is rugged enough to hold a 3,000-pound forging for inspection. Provisions have been made to level and hold the airframe component off the bottom of the tank.

4.2.2 X-Y Scanner

The general configuration of the scanner is shown in Figure 18. It can scan in either the X- or Y-axis and index in the other axis. It can also scan in any vector direction in the X-Y plane. The unit was assembled primarily from purchased parts, but some parts were manufactured and assembled by the Tooling Department.

The scanner frame is constructed from an aluminum U-channel and bolted to the top of the tank. Support blocks made by Berg, Inc. support the complete structure located on top of the immersion tank. On both sides of the tank steel shafts, one inch in diameter are supported by the Berg support blocks and are mounted to run parallel to the X-axis. Four ball-bearing support brackets carry the bridge. These are fastened to two aluminum blocks that carry two one-inch ground rods that act as supports for the Y-axis movement (platform).

DC stepping motors are used to drive the 5 axes (X, Y, Z, θ, $\emptyset$), and position encoders are used to provide the position of the five coordinates. The X, Y, Z, θ, and $\emptyset$ drive motors can be controlled in manual, automatic, or closed-loop computer modes. Figure 18 is a photograph of the scanner control console and ultrasonic unit.

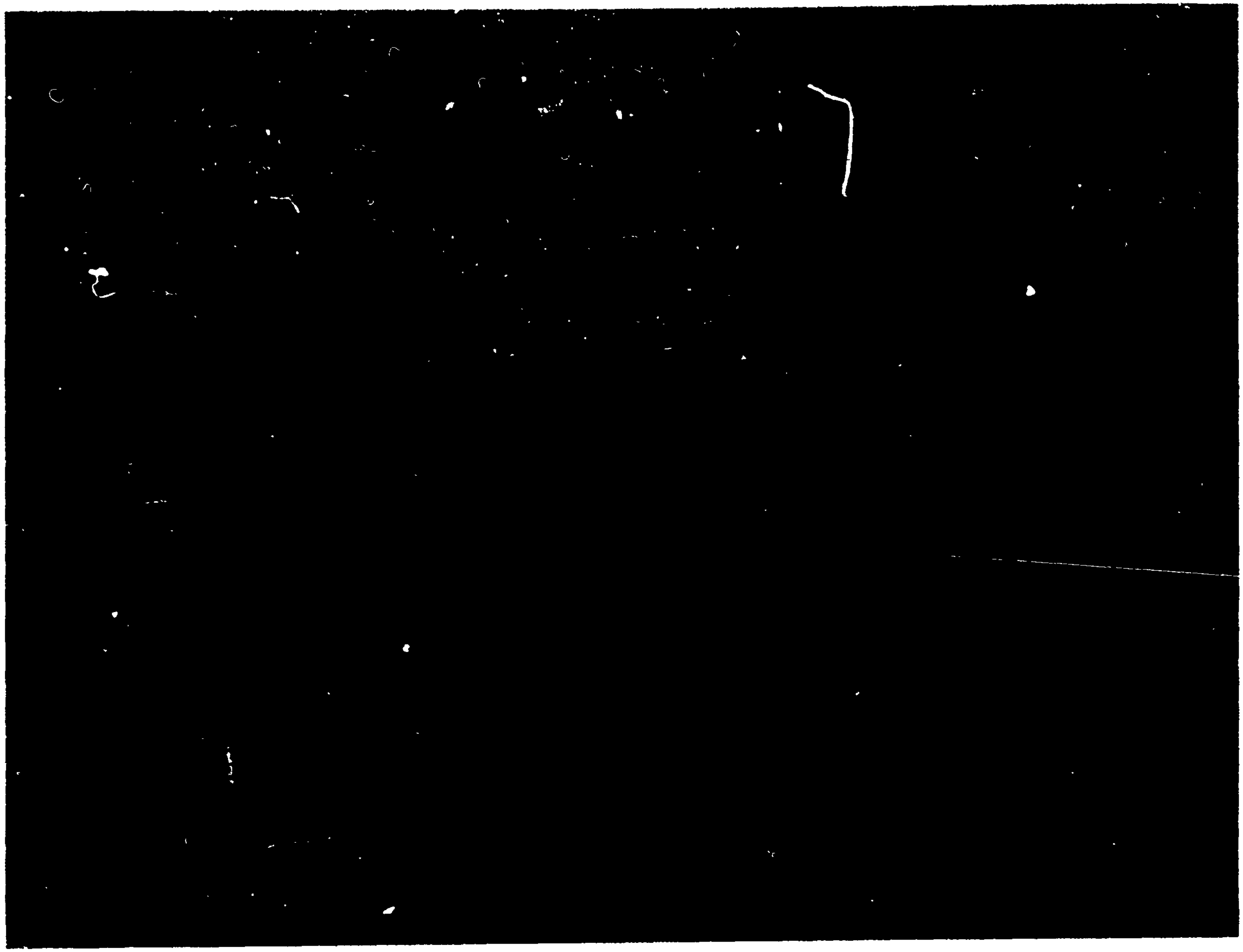


Figure 18 AFML Scanner Control Console with Ultrasonic Unit and Display System

The drive motors and gear boxes are positioned on the support frame and drive the bridge and platform through three sets of POW-R-TOW cable chains. Two sets of chains, one on each side of the bridge, are driven from a common line shaft to reduce the bending movement on the bridge. One long chain is wound around in the pattern shown in Figure 19 to drive the platform. As the bridge moves, the platform stays in the same relative position with respect to Y movement.

A more detailed description of the scanner and its control system is presented in Appendix C.

4.2.3 Manipulator Assembly

Two different types of commercial manipulator assemblies were studied. The approach selected used a modified Automation Industries US 743 search tube and manipulator top with a special transducer head and gimbal assembly built by General Dynamics. The method of maintaining normalcy for the stringent angular requirements of the program necessitated a special design for the manipulator.

The manipulator is shown in Figure 20. The function of this unit is to manipulate the transmit/receive transducer in three axes: vertical, rotation, and tilt. Each function can be accomplished manually with independent and separate controls, or all of them can be operated together as a system to give automatic transducer standoff distance and normality (90°) control.

Each function has a separate motor, motor control encoder, and display that are discussed individually later. Position data from all three functions are fed by line drivers to the computer. The manipulator assembly, which moves vertically and does not include the vertical stepping motor and the cast housing it, weighs approximately 30 pounds.

4.2.4 Gimbal Assembly

The gimbal assembly houses the transducer rotate and tilt mechanism and attaches to the lower end of the manipulator. This assembly, designed and built by General Dynamics, moves the transducer through 360° degrees of rotation and 180° degrees of tilt. A picture of the gimbal assembly is shown in Figure 21.

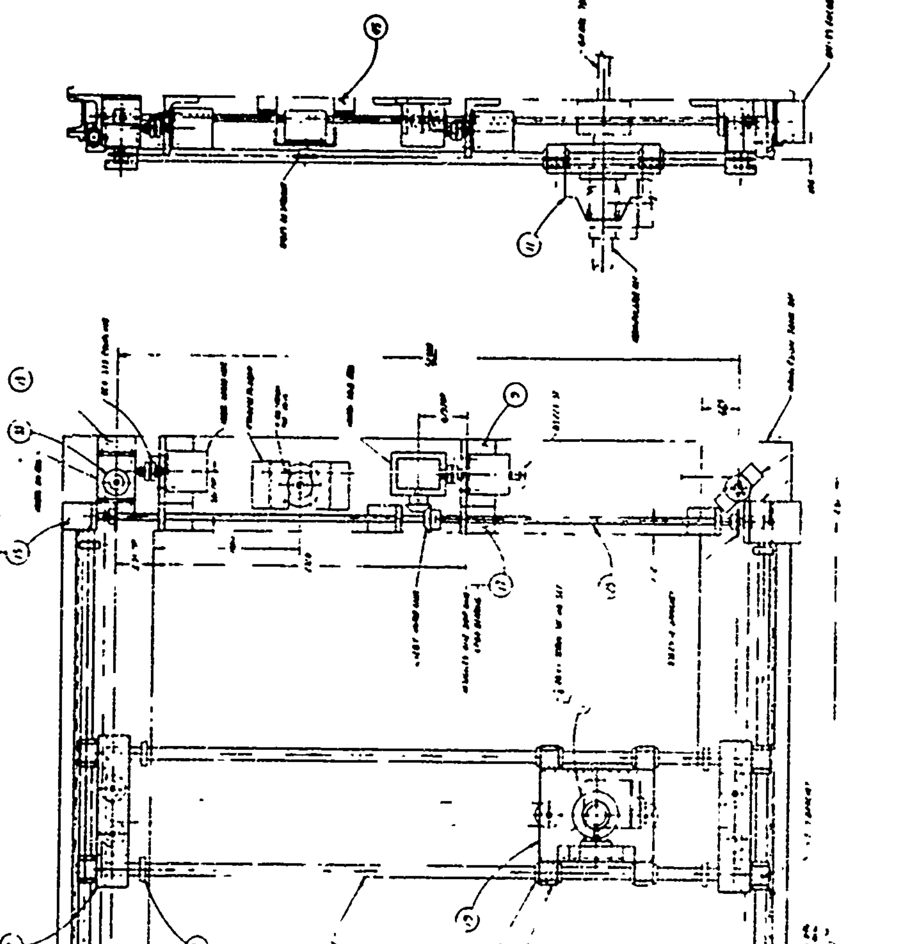


Figure 19. X-Y Scanner System

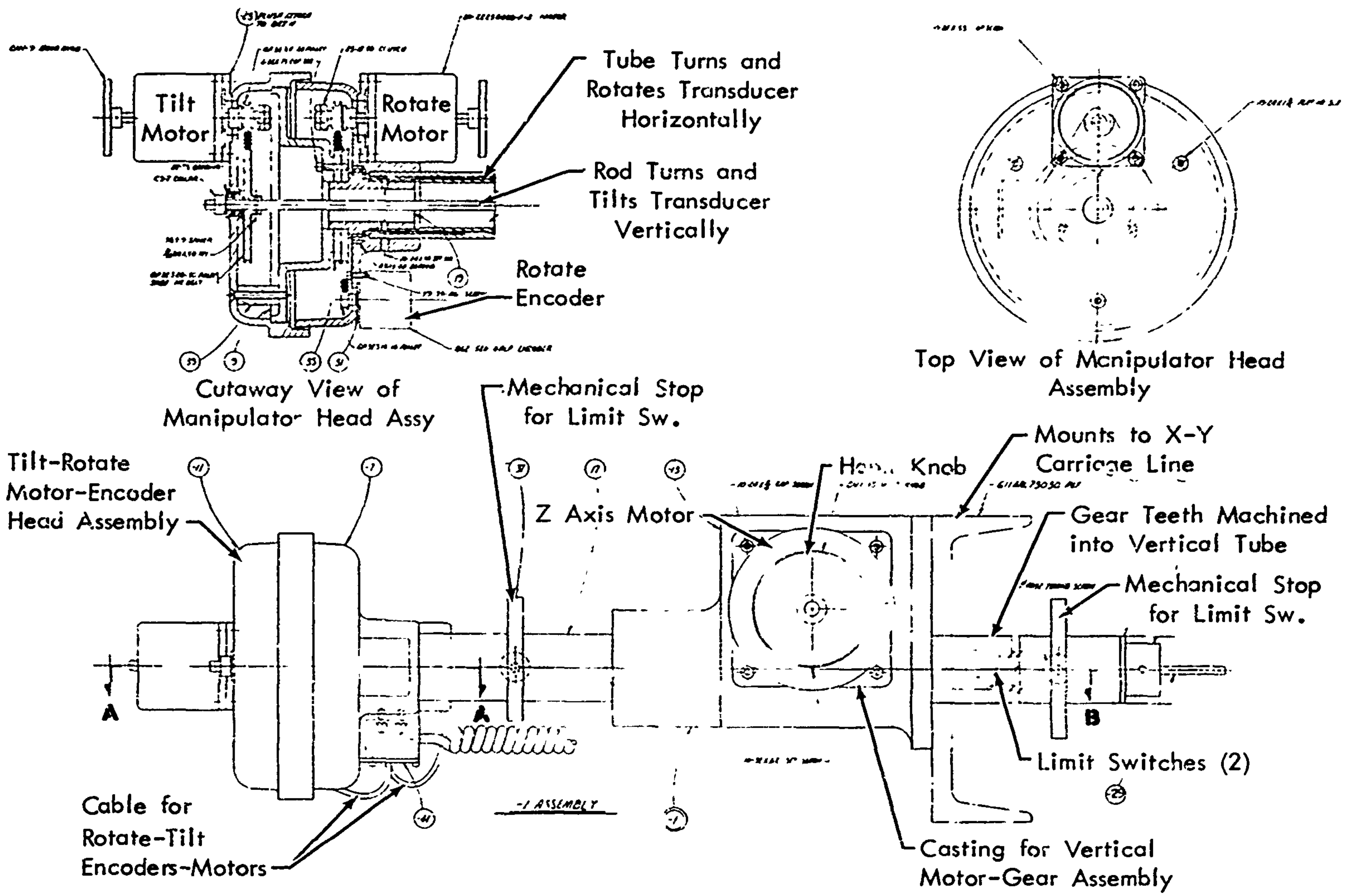


Figure 20. Vertical-Gimbal Manipulator Assembly

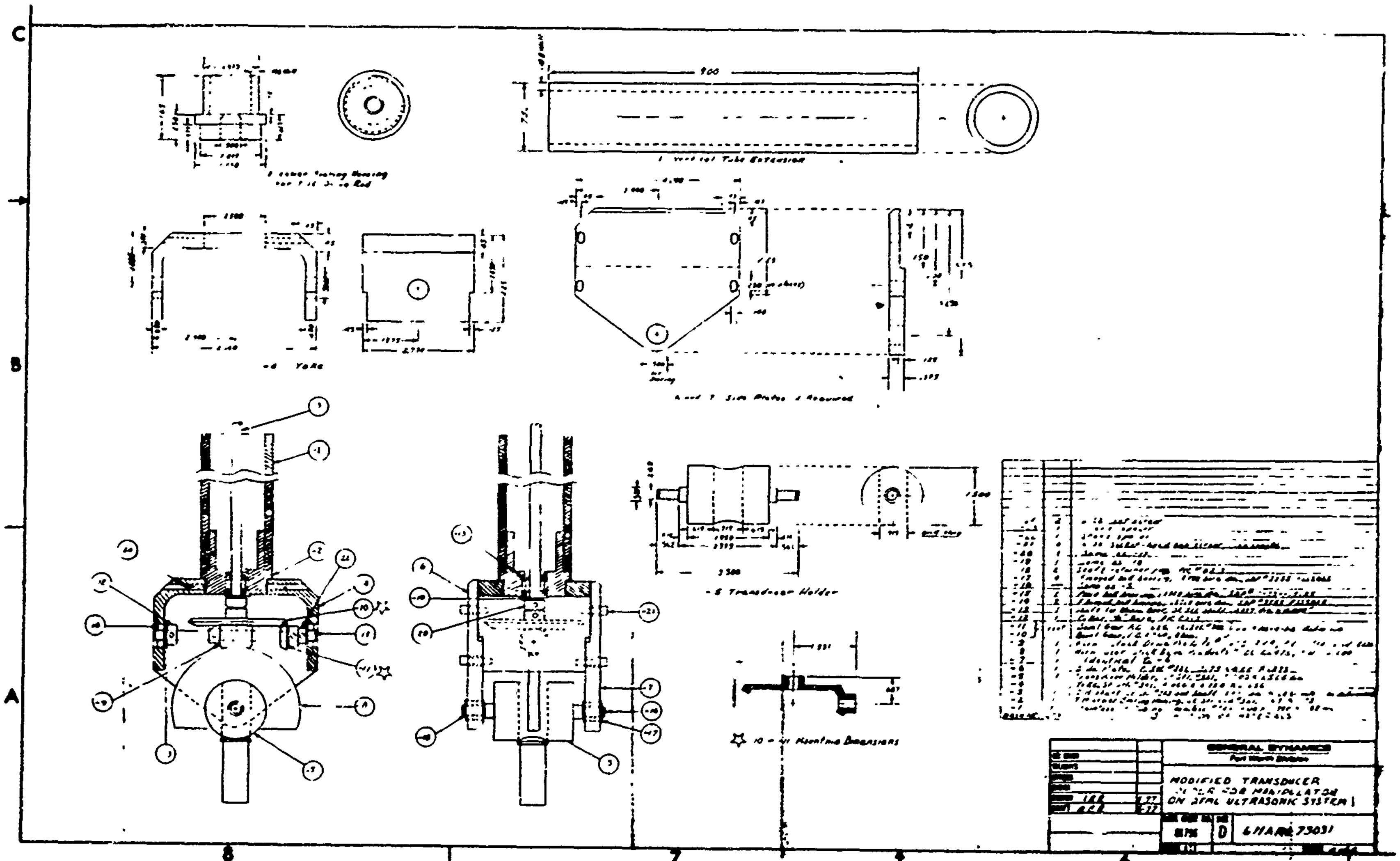


FIGURE 21. Modified Transducer Holder For Manipulation On AFML Ultrasonic System

4.2.5 Scan-Speed Improvement

The X and Y drive speeds of the five axes of the CAUIS were the primary constraints which limited the overall scanning inspection speed of the system. To improve the X and Y scanning speeds, new motors with 500 oz.-in. of torque were purchased and installed on the X and Y drives to replace the old 250 oz.-in. motors. The electronic motor drives were modified to give the maximum amount of power to each of these new motors. After these modifications, the X and Y scan speeds were increased to 10 in/sec., which is the maximum speed command that can be given from the computer interface and controls. If the X and Y axes are driven simultaneously at the same speeds the transducer moves at a 45° angle and the transducer speed can exceed 10 in/sec. However, on short moves in a single axis, the time for the ramp up and ramp down of the motor must be taken into consideration and the average speed is reduced below 10 in/sec.

A new electronic motor drive was installed in the Z axis, which resulted in a slight increase in speed for this axis. Further modifications could be made to increase the Z axis speed if necessary. There were no changes in the speeds of θ and $\emptyset$ drives which are the tilt and rotate axis of the transducer. The old speeds and the latest speeds are shown in Table 4.

TABLE 4. MANIPULATOR-DRIVE SCAN SPEEDS

Axis	Previous Drive Speed	New Drive Speed	Previous Average Speed	New Average Speed
X	4"/sec.	10"/sec.	3"/sec.	7"/sec.
Y	10"/sec.	10"/sec.	6"/sec.	7"/sec.
Z	3"/sec.	4"/sec.	1½"/sec.	2"/sec.
θ	45°/sec.	45°/sec.	No change	No change
$\emptyset$	45°/sec.	45°/sec.	No change	No change

4.3 Computer System and Software

Their subsection describes the computer hardward and software configuration at the completion of the technical phases of the contract.

4.3.1 Hardware Configuration

The Digital Equipment Corporation (DEC) PDP 11 Model 45 Computer is the center of the system. Figure 22 is a block diagram of the system.

Central Processor Unit: The central processor unit (CPU) controls the time allocation of the UNIBUS for peripheral operations and performs arithemetic and logic operations and instruction decoding. The processor can perform data transfers between I/O devices at a maxmimum rate of 0.1-million 16-bit words per second.

Memory: The system utilizes 28K 16-bit words of random-access memory (RAM) divided into two types: core and MOS solid-state. There are 24K of core (900 nsec) and 4K of high-speed solid-state memory (450 nsec). The 4K of MOS memory resides in the upper 4K of the system (24K to 28K). This configuration was chosen to take advantage of the faster operation speed in the program-execution section of the memory stack.

Disk System: The RK disk system is a standard DEC device. The RK11 controller is capable of controlling 8 RK5 drive units, each of which has an average access time of 70 milliseconds, data transfer time of 11.1 microsecond per word, and a storage capacity of 1.2-million 16-bit words. The disk system used on this program contains 2 RK5 drive units giving a total storage capacity of 2.4-million words.

A more detailed discussion of the computer hardware is given in Appendix D.

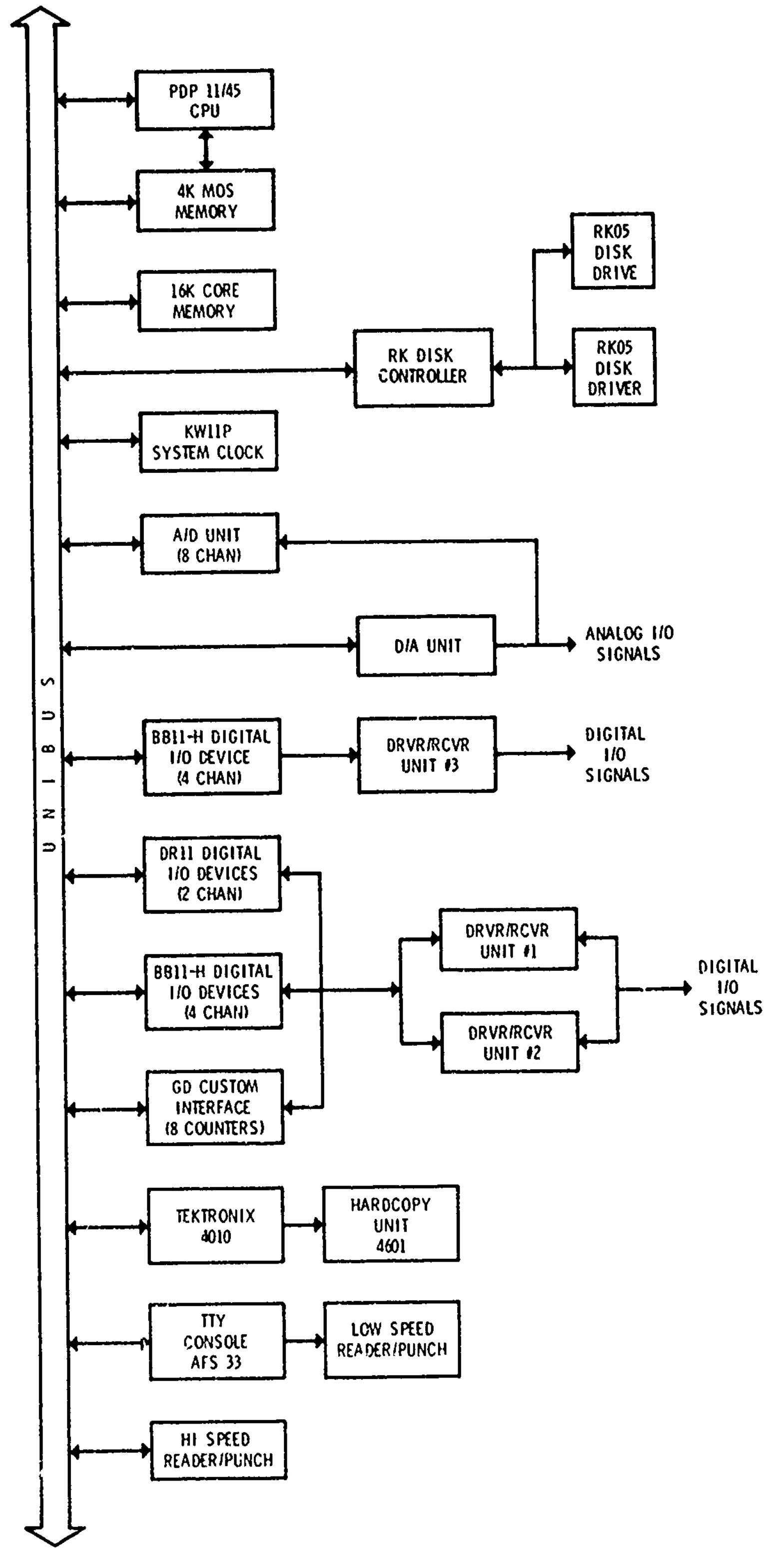


Figure 22. Computer System Configuration

4.3.2 Software

The software necessary to automate the inspection of components with ultrasound (using a reflection mode ultrasonic technique), to perform analysis on inspection results, and to process ultrasonic information (RF signals) for spectroscopic analysis resulted in the development of a data acquisition program (AUISCM) and a post-processing program (POSTPR).

The programs were developed using Digital Equipment Corporation disk operating system Version 8.02 on a PDP 11/45.

The program size in certain cases made the use of overlays necessary. A program that uses an overlay structure is divided into functional segments that need not be in computer memory (core) at the same time. As each function is required, the overlay is loaded into memory. Figure 23 shows the overlay structure used in this program.

Programming Languages: The two languages that were used to develop the software for the system are PDP-11 Fortran IV, which conforms to the American National Standard Institute (ANSI) FORTRAN IV specification, and MARCO 11 assembly language for the PDP-11 family of machines.

The assembly language coding comprises about 58% of the software the majority of this being in the data acquisition part of the program, where the advantage of operating speed, flexibility, and core usage are best utilized. Fortran was used mainly in the pre-inspection phase of the program, where core size and speed of operation were not critical. The post-processing routines are 99% Fortran coded.

Disk System: The software programs provide computer control of the ultrasonic inspection system in a real-time environment, analysis the sensor data for indications of anomalies on disks, and generates flaw data (displays and reports). (See Appendix E for detailed algorithms and flow charts.)

The computer has been programmed to aid the operator in preparing a complete record of the ultrasonic test. The program is versatile so that needless repetition of the input parameters can be avoided by proper selection of the command string.

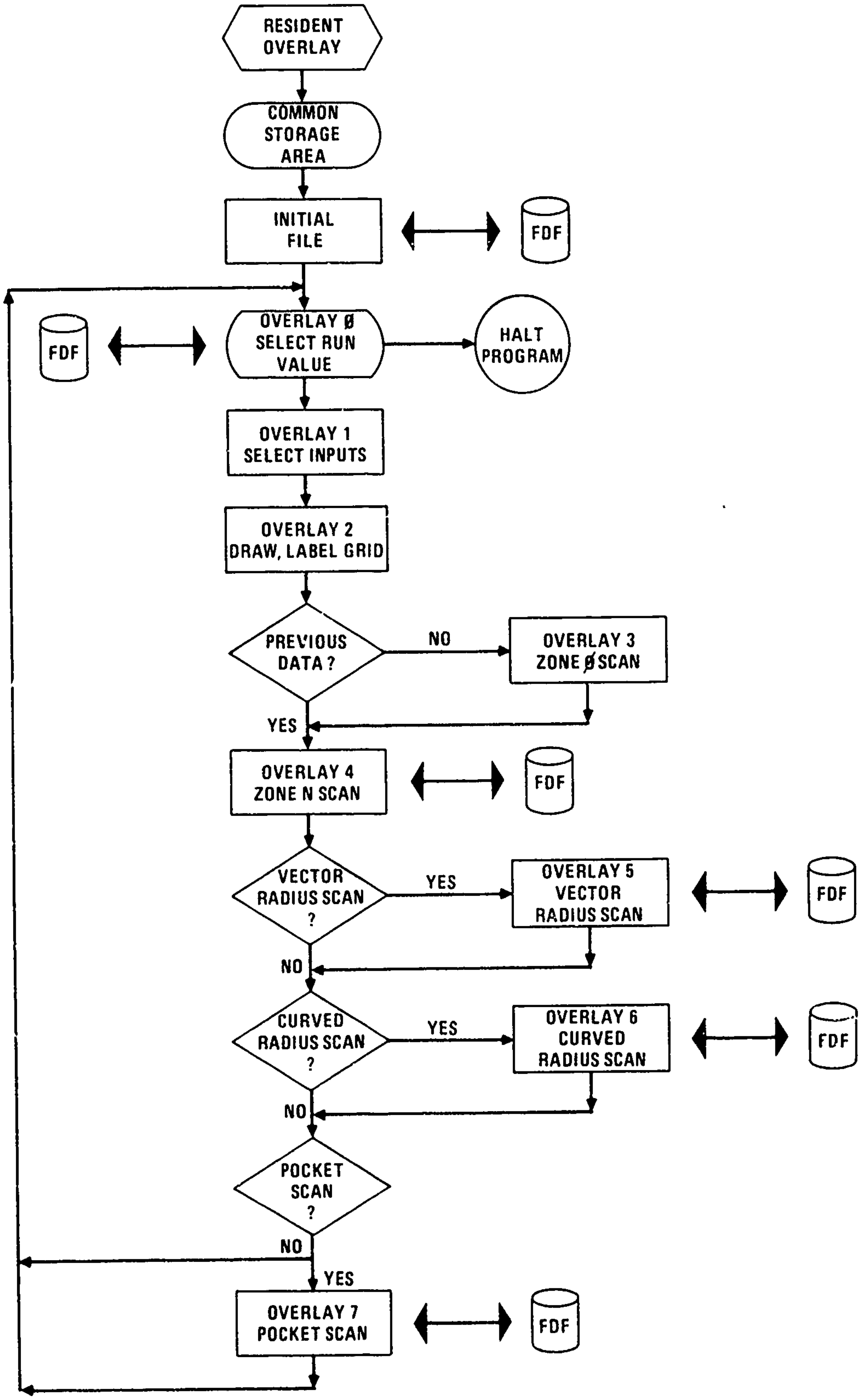


FIGURE 23. Flow Diagram of Resident Main

At the beginning of the program the operator has to select the type of input and test to be performed. This selection is listed under the heading of run mode as presented below. The operator response to the question or run mode tells the computer how to prepare for the subsequent operation. The operator can reply with any of the following responses:

Question	Operator Response	Computer Response
Run Mode =	INITIAL	Prepare new data files and prepare for new input test description files. Remove data from DK1. Clean the disk.
	DATA	Prepare to take data using the previously input test description files. A new run number must be given to each scan to separate the files for retrieval.
	LIST	Prepare a list of the run and part name, scan mode, and % of disk used for the disk park that is on DK1 (top drive).
	DELETE	Deletes the last data run and specimen input information from DK1.
	EXIT	Stops the program operation and returns the computer to the DOS monitor control.

4.4 Peripheral Equipment

4.4.1 Data Display System

The data display system used for the computer-automated system is the Tektronix 4010 computer display terminal. This system is interfaced with the PDP 11/45 computer as well as the Tektronix 4610 hard-copy unit. The user controls the inspection and data manipulation from the teletype and the results may be sent to the Tektronix 4010 for viewing. The computer generates data from the scan, and the 4010 can display these results directly or they can be displayed in the form of point plots to show the location of flaw data.

4.4.2 Hard-Copy System

The Tektronix 4610 hard-copy unit, which is interfaced with the PDP 11/45 and the Tektronix 4010 computer display terminal, may be used to generate a permanent copy of the displayed data. The hardcopy unit can be activated from the 4010 terminal or from the computer.

4.4.3 Digitizing System

Two sets of equipment digitize RF waveforms. One set makes use of a HP175A scanning scope with a 1726A plug-in which has a vertical output and horizontal input that are interfaced to the computer via A/D converters. Operating in conjunction with a HP scope is a Tektronix Type 555 scope. This scope essentially serves as a delay line for the display of the desired portion of the waveform for digitization. The time required to digitize 256 points with this approach is about 2-3 seconds. The second set of equipment for RF digitization is an Inter-Computer Electronics, Model PTR 9300, pulse transient recorder. Both sets of equipment are available for RF-waveform digitization.

SECTION V

CONTOUR SCANNING/FOLLOWING METHODS

Several contour-following methods were considered in arriving at a technique for inspecting components having complex curvatures, such as fillets and small radii. The methods considered included mechanical devices, software, control procedures, and various combinations of these. The mechanical methods studied included:

1) Mechanical probes with microswitch stops
2) Capacitance probes with non contact stops
3) Ultrasonics transducer arrays
4) Eddy current proximity sensors
5) Laser optical sensors

Among the software control methods evaluated were:

1) The use of numerical control tape (NCT)
2) Use of Computer-Aided-Design Data Control (CADDC)
3) A new technique referred to as ultrasonic zone scanning (UZS)

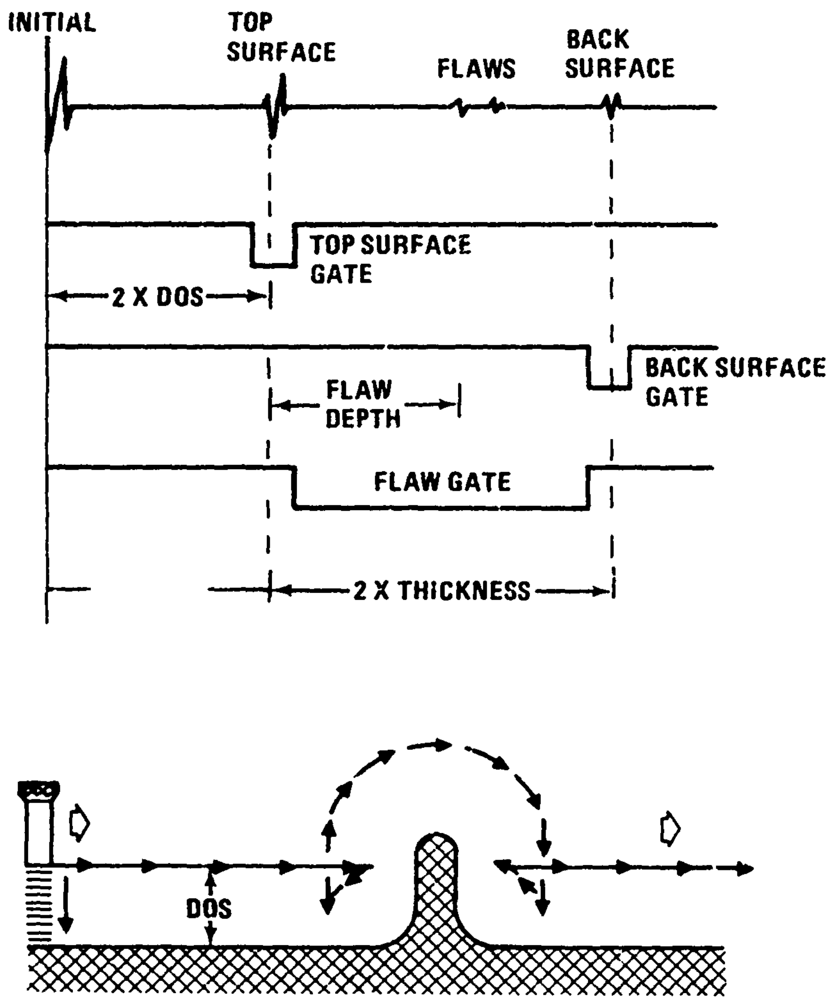
The methods evaluated that combine the so-called mechanical and software methods include:

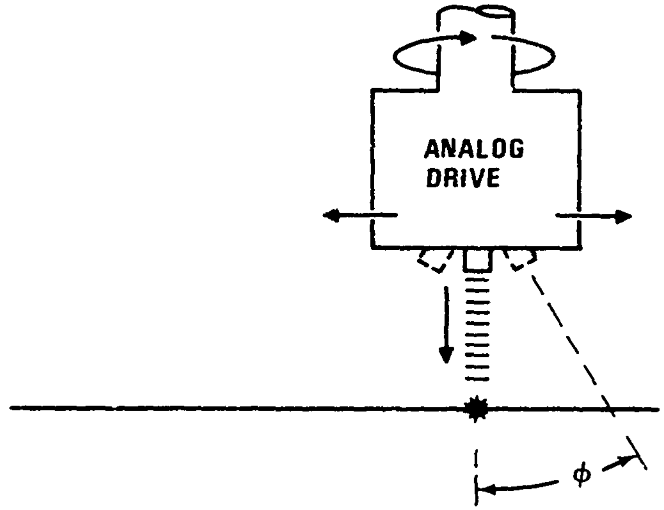
1) Vector drive scanning
2) Vector drive scanning with self-organizing control

5.1 Contour Following

The contour following approach for inspecting complex airframe components is depicted in Figure 24. As indicated by the ultrasonic echo signals and control gates in the upper left-hand side of the figure, the scanning transducer must be kept normal to the top surface of the specimen and at a constant distance of separation (DOS). When an arbitrary path (lower left-hand sketch) is scanned across a specimen, the peaking and scan path controls limit the scan speeds attainable. Often it is difficult to avoid collision with projections from a complex component. An attempt to increase the scan speed of this contour following procedure occupied a large portion of the early phases of this contract.

CONTOUR FOLLOWING





- HIGH SPEED SCANNING WITH PLANE GEOMETRIES AFML #1
- REASONABLE SPEED WITH SYMMETRY OF ROTATION PW#1
- VERY SLOW FOR SYSTEMS HAVING COMPLEX GEOMETRIES eg. F-111 LANDING GEAR FORGING.

REASON: TIME REQUIRED FOR NORMAL SEEKING (PEAKING) AND FOR ADJUSTING DOS

FIGURE 24. Pulsing Gates and Contour Following

5.2 Methods of Evaluation and Selection

The first three of the mechanical methods listed above were evaluated in the previous AFML contract (F33615-72-C-1828). The rationale for rejecting Methods 1 and 2 are discussed in Ref. 1. The multi-transducer ultrasonics methods, however, were more fully tested when four 1/8-inch diameter transducers were used to monitor standoff distances and maintain normalcy between an incident ultrasonic beam and the surface of the component. The advantages and limitations of the ultrasonic transducer array method is described in a previous report (Ref.1) . The vector drive method (Ref. 1) for contour following increments the searching transducer by a desired distance in a vector direction and simultaneously maximizes the front surface reflected ultrasonic signal and interrogates for flaw signals. This method was used extensively for inspection of complex airframe and engine components. The smallest radii that could be followed by this method, however, was found to be 3/4 of an inch.

An objective of the present contract was to develop a procedure to follow radii as small as 1/8 inch. Trying to achieve this objective, eddy current and laser optical sensors were evaluated (paper study only). The laser method was rejected after it was found to be inconsistent with miniaturization of the ultrasonic transducer assembly for flaw inspection in small-pocketed areas of complex airframe components. The eddy current method was also rejected since a way could not be found to contour follow radii any faster than ultrasonic methods can.

In view of the objectives of the present contract, it was concluded that none of the mechanical methods was viable for contour following a 1/8-inch radii and still achieving an economical inspection of at least 6 inches per second over complex-shaped airframe components. This conclusion was also drawn by PAR after studying the vector drive using self-organizing control. Signal peaking, required to maximize the front-surface reflected signal at each end point along a scan vector, was concluded to be so time consuming that it is impossible to achieve an economical inspection speed.

Three software methods NCT, CADDC, and UZS are useful for inspecting complex airframe components and still achieving the scan speed objective of this contract. The major efforts and resources of this contract were devoted to developing these three methods.

The NCT and CADDC methods provide final dimensions of an airframe component in a convenient format to be stored in the mass memory of a digital computer. Such component dimensions can be utilized by computer software to command the five-axis mechanical drive system to contour-follow the component being inspected. The details of the CADDC method are presented in the final report by PAR (Ref. 10), which describes their subcontract effort in this program.

Ultrasonic zone scanning has received the largest emphasis, and special hardware and software required to implement this method has been developed. Illustrative inspection results obtained by the zone-scan method are included in Section 7; principals of operation for this method are described in the next subsection of this report.

5.3 Ultrasonic-Zone-Scanning Method

The ultrasonic-zone-scanning method makes full use of the mechanical, electronics, and digital capabilities of CAUIS. Its implementation is complemented by the objectives of this contract as follows: (1) economic scan speeds of around 6 inches per second, (2) optimization of the CAUIS for production applications, (3) capability of a high percentage of volumetric inspection of complex air-frame components, and (4) miniaturization of transducer head assembly for inspection of small-pocketed areas. In zone-scanning, inspection scans are made primarily in the X-Y plane where both X- and Y-axis scan speeds of 10 inches per second can be achieved; therefore, a large percentage of the components can be inspected at speeds greater than 6 inches per second.

The ultrasonic-zone-scanning method, outlined in Figure 25, generally operates as follows:

1) The component to be inspected is placed randomly on a back-up plate in the ultrasonic tank.

2) A time gate is set to record only the reflected signal from the bottom of the tank. An X-Y scan is made. This X-Y scan (referred to as Zone Ø) gives the outline and projected image of the component from which its total cross-sectional area may be computed. Figure 26a shows a Zone Ø scan of Component I, which is essentially the outline of the part. To increase the total volume

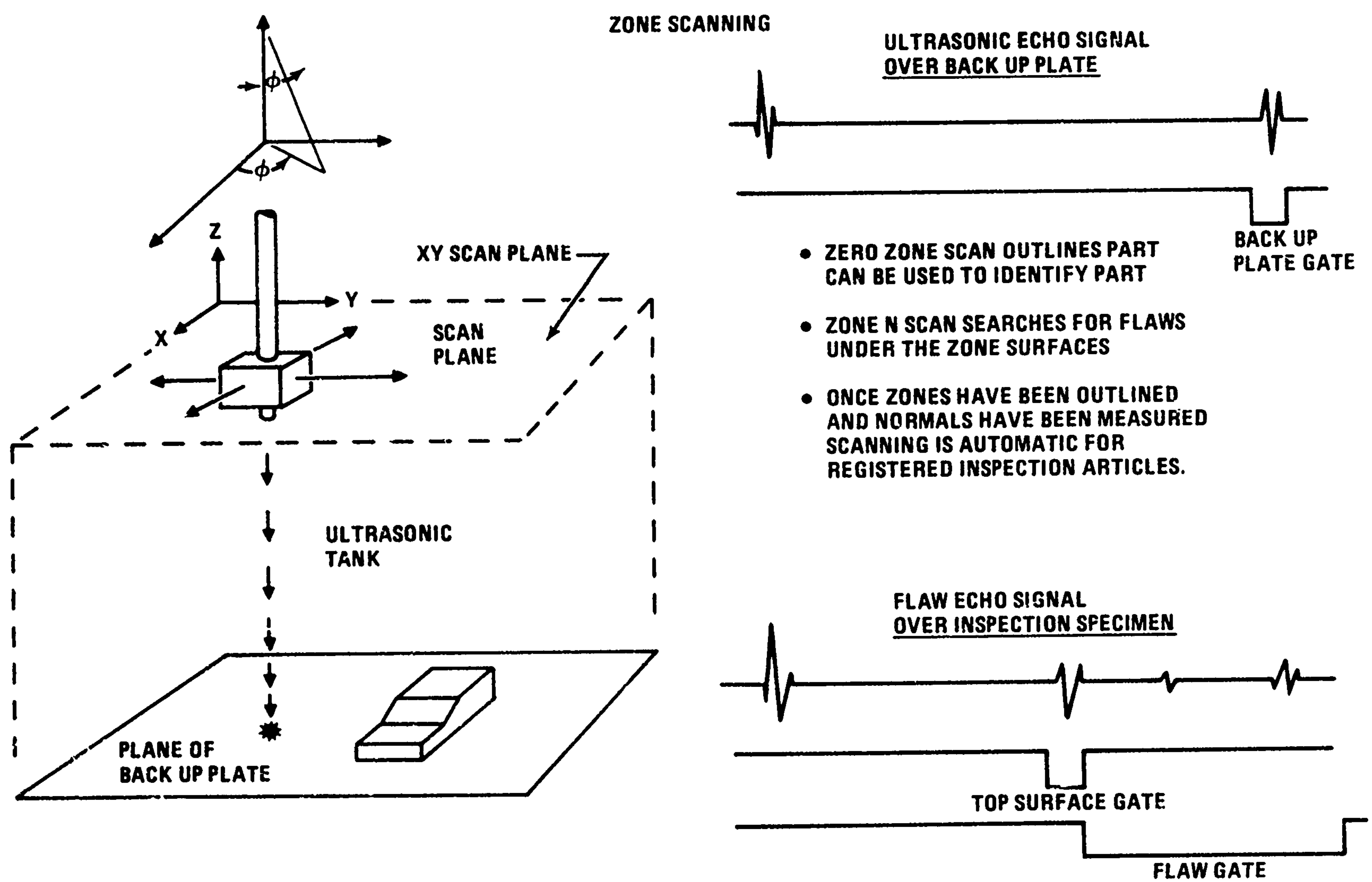


FIGURE 25. Zone Scanning and Ultrasonic Signals

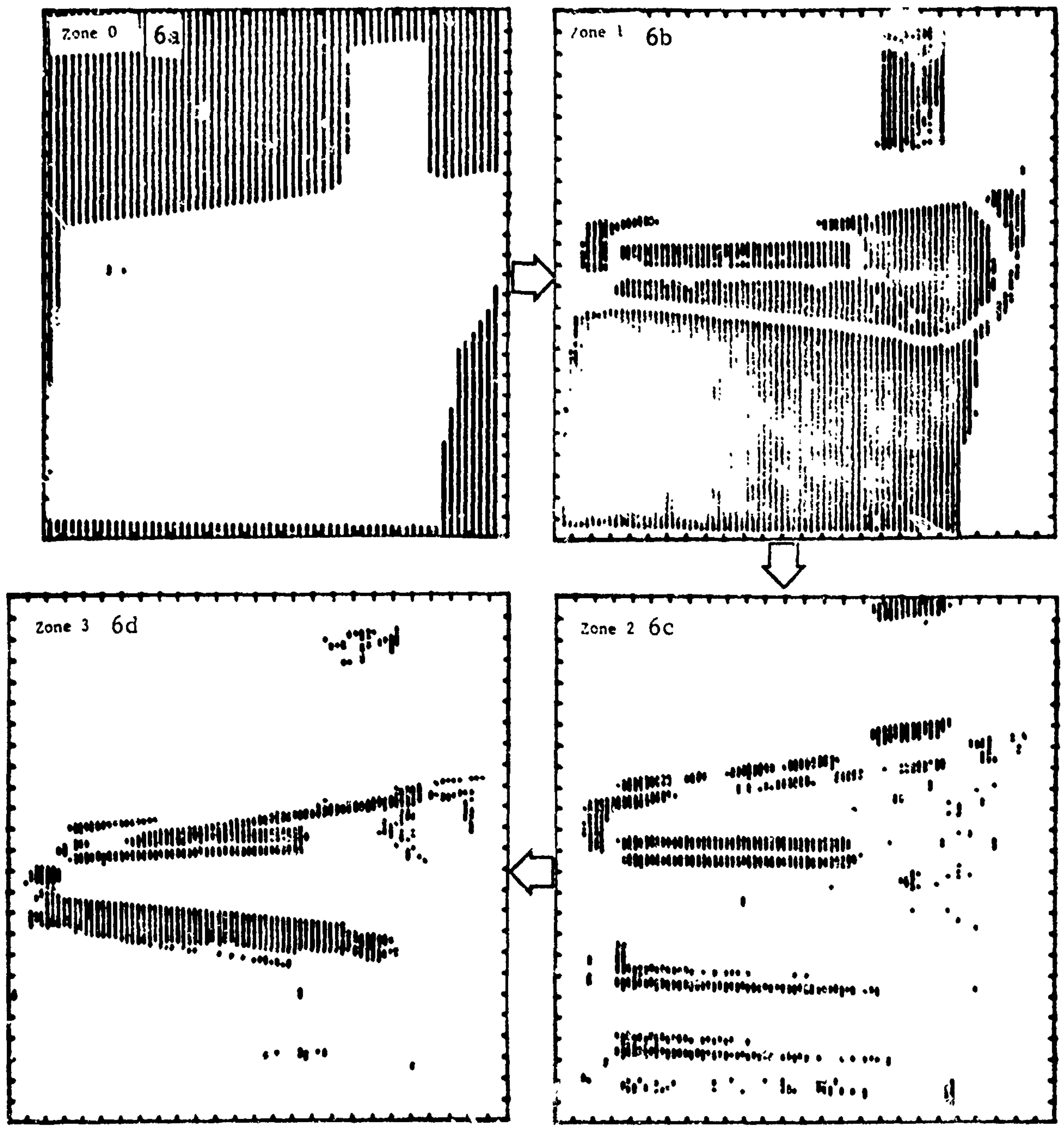


FIGURE 26. X-Y Scans of the Landing Gear Forging (Component I) Showing Three Different Zones Which Have the Same Surface Normals.

inspected, a component can be turned over and inspected from the opposite side. Figure 27a shows a Zone Ø scan of Component I, which was obtained by scanning the opposite side from that of Figure 26a. Figure 28a and 29 are Zone Ø scans of Components II and III respectively.

3) The computer will then move the transducer to the component over the largest planar area optionally defined by the operator and normalize the ultrasound beam with respect to the planar area by peaking the signal through adjusting θ and $\emptyset$. An X-Y scan is then made of this area and it is identified as Zone 1. In most cases a component has several pocketed areas all belonging to Zone 1 and, therefore, can be inspected with a single X-Y scan.

4) The blank (white) areas in the Zone 1 scan, lying within the boundaries of the component, have normals different from the Zone 1 plane. A normal to each area must be measured and a new zone scan must be made. In the case of fillet radii or cylindrically curves surfaces, line or multiple-line scans must be made after surface normals are measured. Figures 26b, 26c and 26d show Zone 1, 2, and 3 scans of Component I, and Figures 27b, 27c, and 27d are Zone 1, 2 and 3 scans of Component I, which was obtained by scanning from the opposite side from those of Figure 26. Figures 28b and 28c are Zone 1 and 2 scans of Component II, and Figures 30a and 30b are Zone 1 and 2 scans of Component III. The number of zones to be scanned depends on the complexity of the component, expected flaw orientation, and how thoroughly the component must be inspected. Each one of these three components can have many other zone scans. However, just the combination of Zone 1 and 2 scans of these components can inspect approximately 87%, 97%, and 96% of the volume of Components I, II, and III respectively. Table 5 shows the approximate volume inspected by each of the zone scans for these three components. For near-net-shape or net-shape components such as Component III, one or two zone scans can cover a large volume of the part.

The attractive features of the zone scan method are that: (1) no particular care needs to be taken in leveling a component, (2) the component can be identified from its unique cross-sectional area, (3) a minimum number of scanner-normalization corrections are required, (4) scanning proceeds at scan speeds exceeding 6 inches

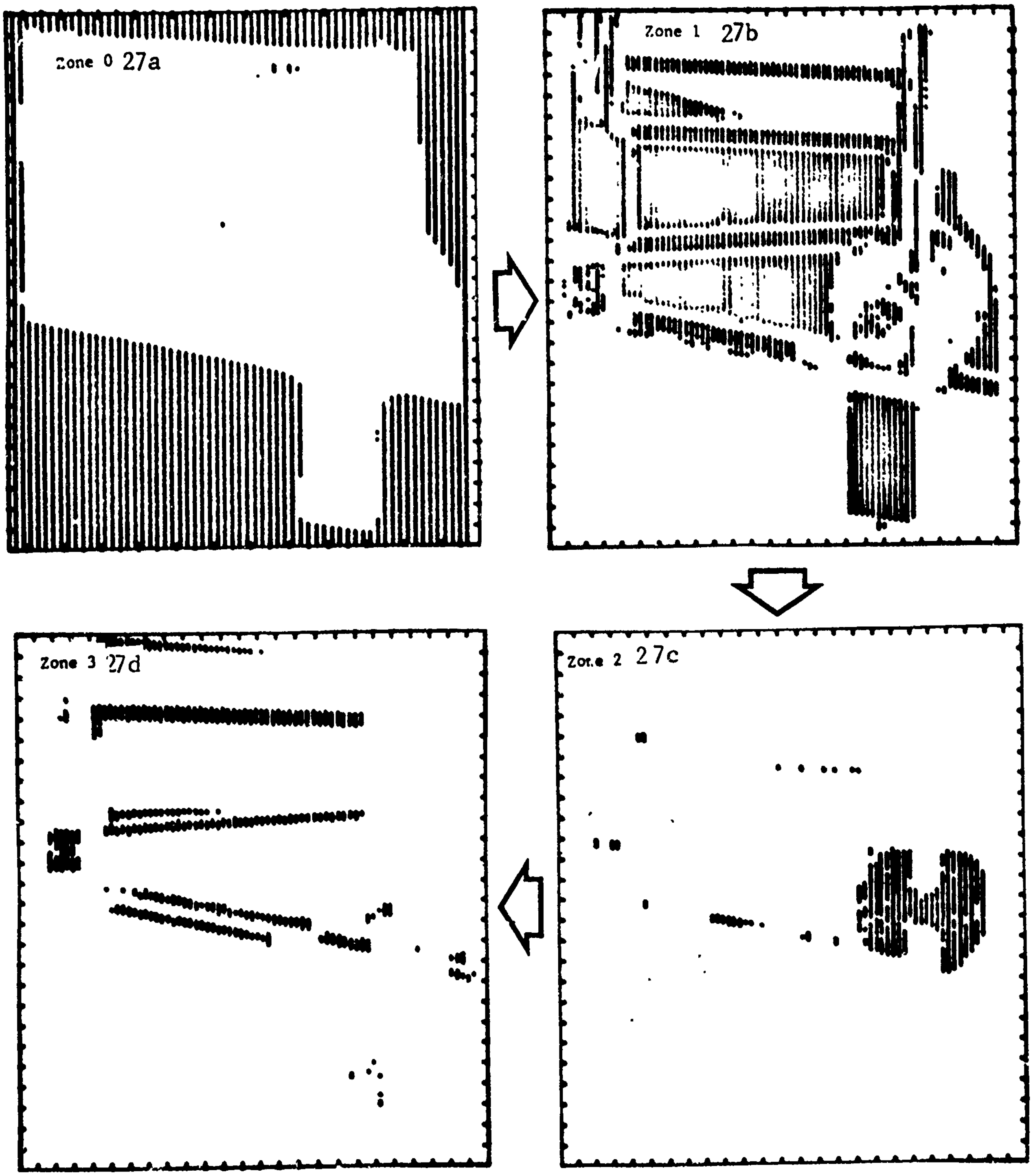


FIGURE 27 X-Y Scans of the Opposite Side of the Landing Gear Forging (Showing Zones Which Have the Same Surface Normals)

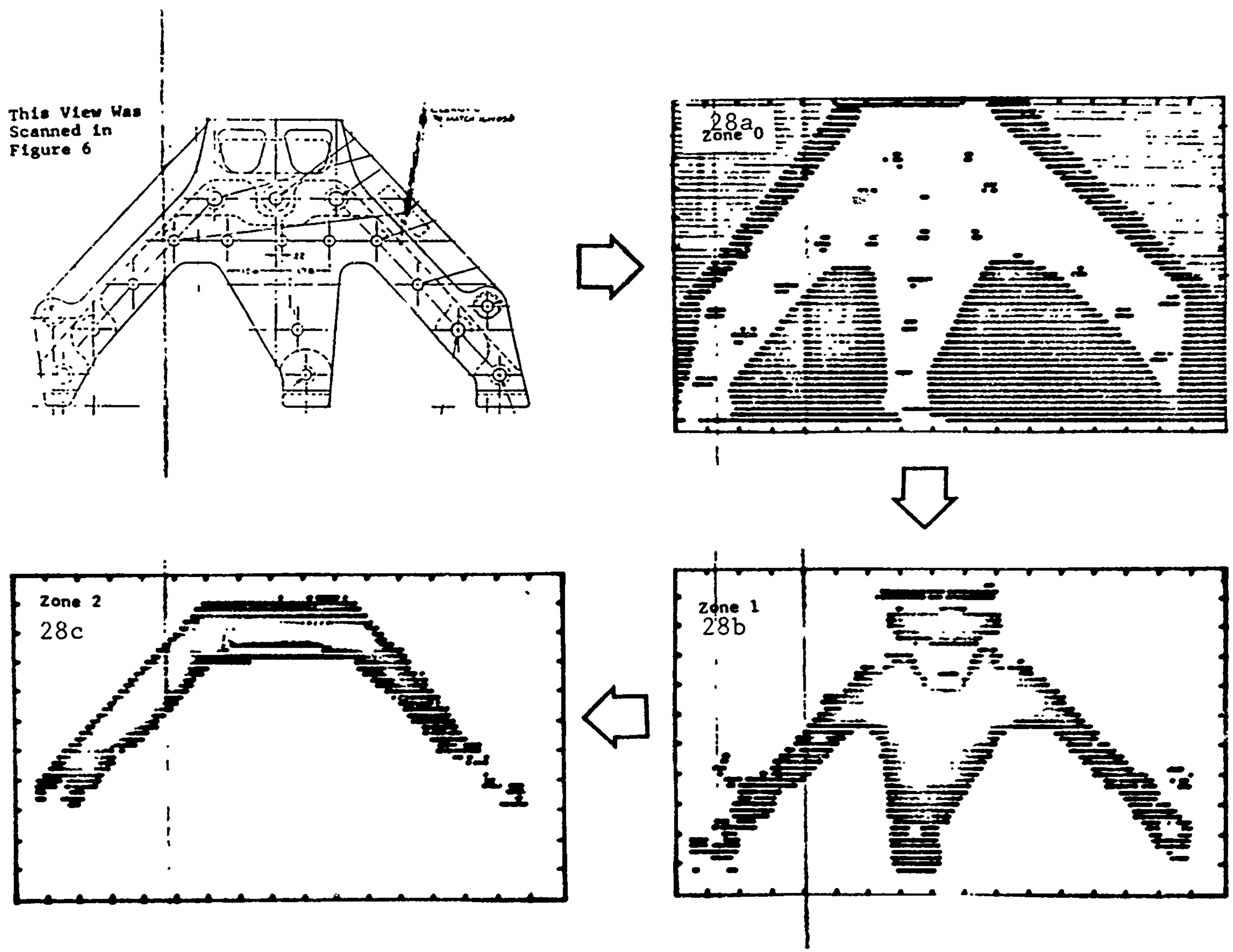


FIGURE 28. X-Y Scans of the Wing Attachment (Component II) Showing Fastener Hole Locations and Showing Two Zones Having the Same Surface Normals

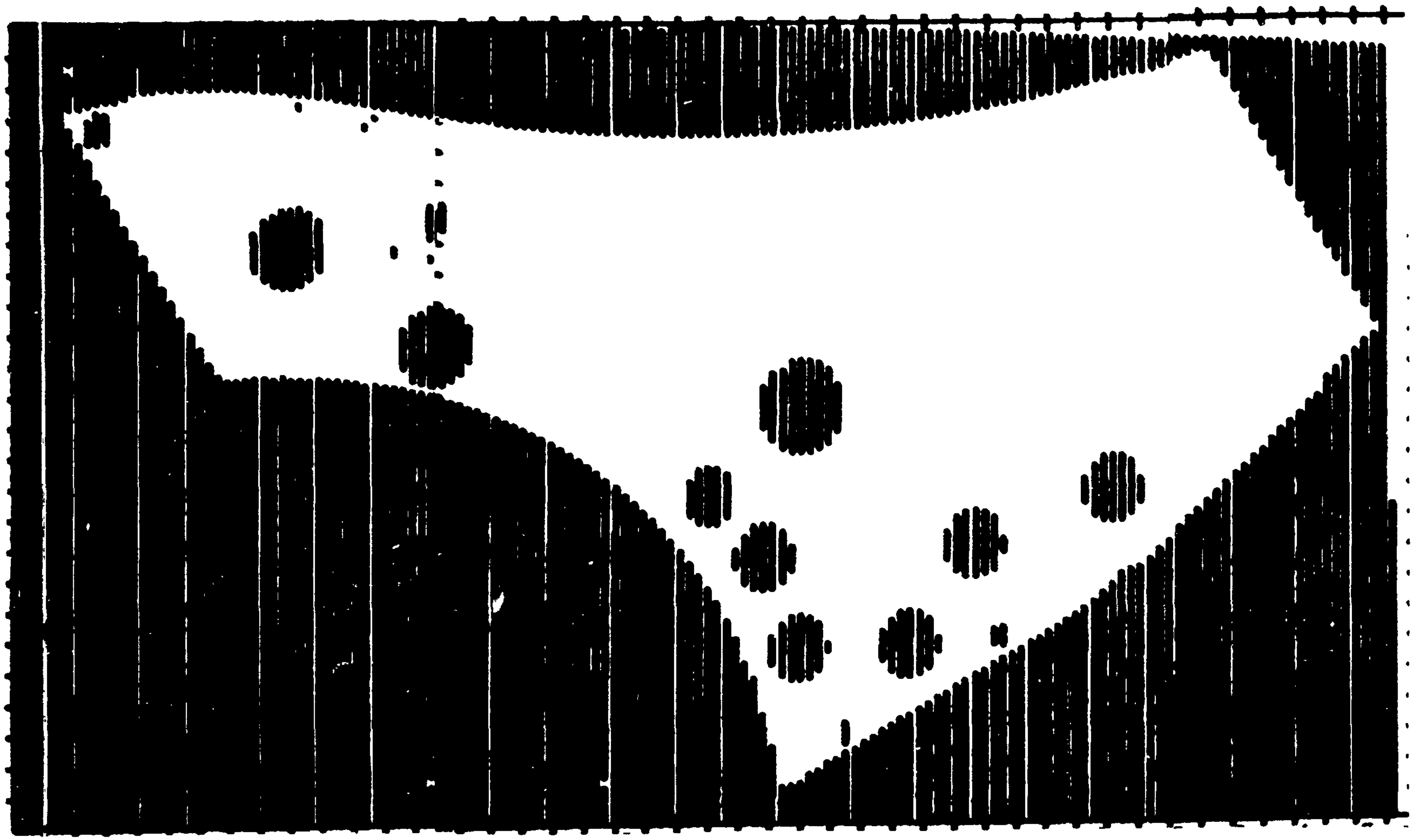
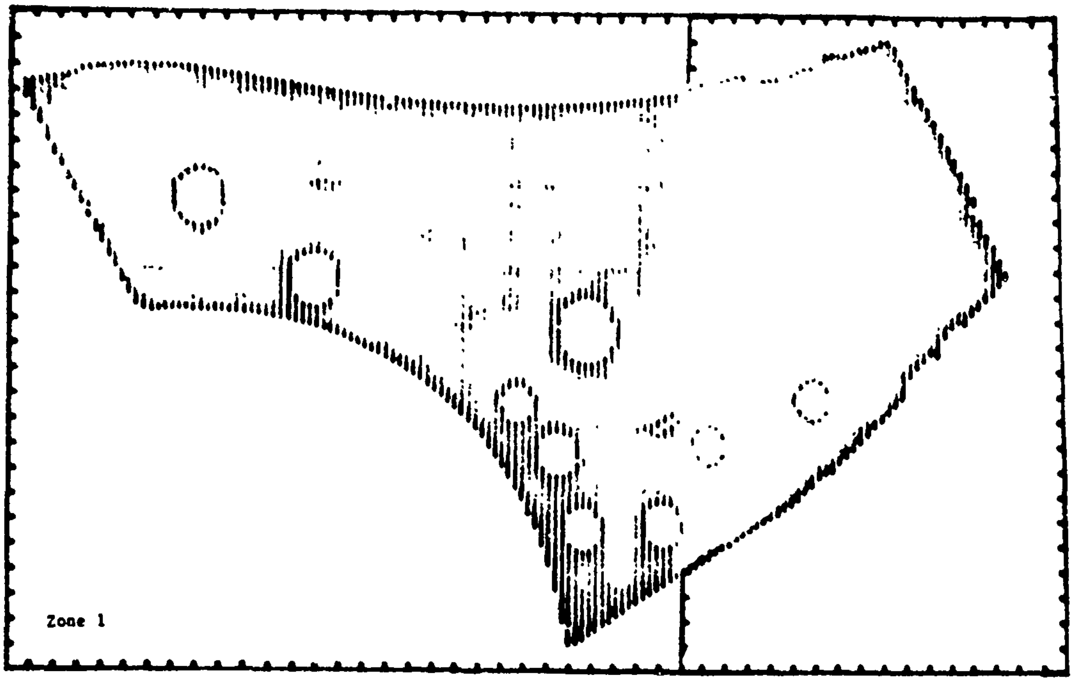


Figure 29, Zero Zone Scan of the Component III
F-16 Bulkhead Forging



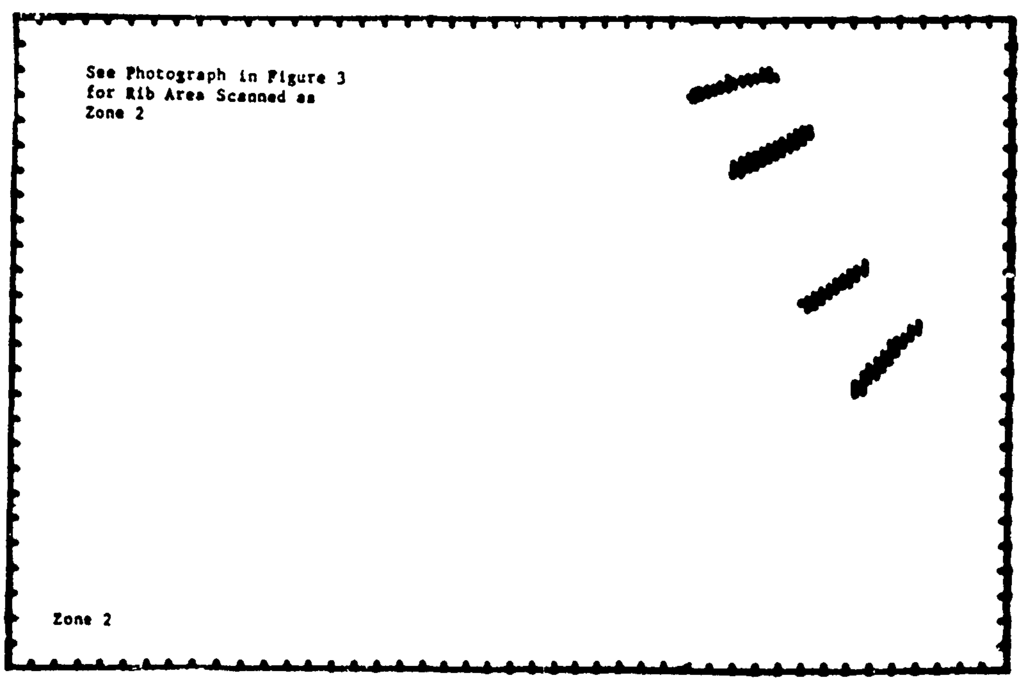


FIGURE 30. Zone One and Zone Two Scans of the F-16 Bulkhead Forging

TABLE 5. SURFACE AREA PERCENTAGES SCANNED BY ZONE SCANNING ALONE

COMPONENT	ORIENTATION	ZONE 1 AREA PERCENT SCANNED	ADDING ZONE 2 AREA PERCENT SCANNED	ZONE 1 + ZONE 2 BOTH SIDES ESTIMATED VOLUME SCANNED
1. F-111 Landing Gear Forging	Top Scan	53%	62%	87%
	Bottom Scan	80%	85%	
2. F-16 Wing Attach Fitting	Top Scan	60%	90%	97%
	Bottom Scan	80%	88%	
3. F-16 Isothermal Bulkhead Forging	Top Scan	~ 90%	~ 95%	~ 96%
	Bottom Scan	~ 90%	~ 95%	

* It is estimated that the volume scanned $\propto$ area scanned.

per second, (5) a very large percentage of most volumes can be inspected quite rapidly, (6) the top-surface envelope is not obscured by a top-surface gate, allowing surface roughness measurements to be made, and (7) areas missed can be rescanned.

5.4 Software for Zone Scanning

The concept of zone scanning was introduced during this contract as an approach to inspecting complex parts for flaws. The concept of zone scanning includes several important steps leading to the completion of a successful scan, namely: Zone Ø scanning, Zone N scanning, radius scanning, curved radius scanning and pocket scanning.

5.4.1 Zone Ø Scanning

The purpose of Zone Ø scanning is to define the boundaries or edges of the part to the computer. This is done by placing the part in the tank on a back-up plate in a predefined square whose size is determined by the operator. The transducer is then placed so that the reflection from the back-up plate is maximized. The front-surface gate width on the signal processing hardware is made as narrow as possible to minimize receipt of unwanted signals and provide for a .050-inch front-surface envelope. The predefined square is then scanned thoroughly with the computer saving X-Y coordinates whenever the back-up plate signal is absent. Component boundary points are then displayed on the Tektronix memory scope giving an outline of the part. The routine used for control of the X-Y scanner and determination of the time at wich data is to be sampled and displayed on the Tektronix memory scope is called CNTZNØ. ACQZØ, another important routine, inputs and saves the data in computer disc memory for subsequent determination of total volumetric inspection of a given component or for displaying of flaw data as isometric projections. The flow diagrams for ACQZØ are shown in Appendix E.

An important portion of software closely associated with Zone Ø scanning is the identification and orientation of a part. Each part and each side of the part scanned are given unique names. The explanation for this is: if a part is scanned once and an identical part is placed in the tank in the same way and identified properly, it may be scanned using the boundary points obtained from scanning the previous part. Whenever this can be done, a significant savings in time may be realized since the Zone Ø scan will be bypassed and zone normals will be known. Note that this is possible only when the part is registered; that is, the part is fixed in the tank in the same manner as the part previously scanned.

This is accomplished by having a solid "stop" attached to the back-up plate. If part registration can be accomplished, the boundary points are displayed in the Tektronix memory scope, and the Zone N scans are executed immediately.

5.4.2 Zone N Scanning

The next step in performing a scan of a part is called the Zone 1 scan, in which actual flaw data are taken and stored for later analysis. The first step in the Zone 1 scan is for the operator to input a set of X-Y coordinates located as near as possible over the largest planar surface in the part. The set of planes containing the same normal is considered to be Zone 1; subsequent planes having common normals will be called Zone 2, Zone 3, etc. The scan lines of the transducer are determined by the boundary points found in the Zone Ø scan. The transducer merely scans between the boundary point for each zone, issuing ultrasonic pulses at given increments. For each Zone N scan, the information stored on disc consists of the zone word, the tilt and rotate values of normalization for this zone, and the index position (new for each scan line). The transducer emits ultrasonic pulses at given increments, determined by the operator in the initialization process, and takes a sample of data. If the transducer is not normal to the part (not over the zone), at the sampling point, a top-surface echo is lost and no data are taken. If the scanner is over the current zone, the scan position and time of transmission to the top surface of the part are saved. On the basis of the information contained within a flag word set by the ultrasonic electronics, a back-surface time and flaw location are saved when applicable. For each set of data saved on disc, a corresponding point is displayed in the Tektronix memory scope showing the operator what portions of the part have been scanned. After the transducer has scanned a complete zone, control is returned to the operator to input another set of X-Y coordinates for a new Zone N scan or to continue to another scanning technique to complete the scan. CNTZNN is similar to CNTZNØ in that it controls the X-Y scanner and determines when data is to be sampled and displayed. ACQZN is likewise similar to ACQZØ in that it inputs and saves the data in computer disc memory for subsequent determination of total volumetric inspection of a given component. The flow diagrams for CNTZNN and ACQZN are shown in Appendix E.

The need for identification and orientation of a part arises in the Zone N scanning technique. If a part were registered and placed against a "stop" when it was scanned, it can be identified and scanned with no operator intervention. The boundary points and normals previously found may be sought automatically and used successfully in scanning various zones of the part.

A software procedure necessary to the accomplishment of a Zone N scan is an algorithm to accurately find the normal of a planar surface. The acceptance or rejection of a given normal is determined from the top-surface reflection in real time by the new electronics hardware. A one-bit flag word is used to designate near-normal incidence. If the bit is set, a top-surface reflection has been detected. With this small amount of information available, an iterative procedure is needed to close in on a normal with as much accuracy as possible. In theory the surface over which the top-surface reflection is sensed is circular or elliptical in nature; therefore, the iterative procedure chosen was one which attempted to approach the center of this region. The flow diagram showing the algorithm for the normalization process is shown in Appendix E.

5.4.3 Radius Scanning

The next portion of software needed to complete Zone N scanning is one to scan radius areas. The major problem in scanning these areas is the normalization to the curved area. From the testing conducted, it was found more advantageous to have the operator manually normalize the transducer. After this is completed, start and stop points in the X-and Y-vector directions are determined. The radius area is then scanned by simultaneously moving the X and Y motors to the desired stopping position. While moving from one X-Y point to the next X-Y point, data is being sampled and saved on the computer disc in the same manner as used for the Zone N scan. After completion of the scan, the area scanned is displayed on the Tektronix memory scope. The flow diagrams for controlling the X-Y scanner, which shows a large reduction in scanning time, and determining when data is to be sampled and displayed are not included since they are similar to the flow diagrams for CNTZNN and ACQZN. The technique for identification and orientation of a part may be used in scanning radius areas in the same manner as it was used in Zone N scanning.

5.4.4 Curved-Radius Scanning

Curved-radius scanning is necessary when an area of the part does not lend itself to Zone N scanning or radius scanning. An example in which this type of scanning is necessary is the circular-radius area on the F-111 forging. This area cannot be scanned using the vector dr .e and does not lend itself to Zone N

scanning since it is not a planar region. By use of curved radius scanning, each point the operator wants inspected must be registered in the computer. This is accomplished by manually normalizing the transducer to each point and signalling the computer to take a reading from the encoders. These points are then stored and may be used on subsequent runs.

5.4.5 Pocket Scanning

A special section of software was written to scan pocket areas on the F-16 Isothermal Bulkhead. The scanner control for pocket scanning is a combination of vector radius scanning and curved-radius scanning. When the scanner is moving along the sides of the pocket, vector radius scanning is being used. When the scanner is turning a corner, curved-radius scanning is being used. In order to scan these areas, a mirror was placed on the end of a 3/8 inch focal transducer (focal point is 3 inches). After registration of all points in the pocket, the transducer moves around the pocket and increments after every revolution until the upper limit for Z is reached.

Examples of zone scanning, radius, curved radius, and pocket scanning results will be discussed and shown in the next section of this report.

SECTION VI

GENERAL SYSTEM CAPABILITIES

This section describes some of the optimized CAUIS capabilities in real-time flaw-data presentation and post-inspection signal-processing techniques for flaw-detection enhancement. Some of the capabilities were developed in the previous AFML CAUIS program and others were developed in the present contract. To be complete, all the capabilities are presented in this section.

6.1 Data Display Techniques

This subsection describes the different types of flaw-display modes that the system is capable of providing. The primary display for the initial inspection is the conventional C-scan recording. The post-inspection mode allows the operator to expand a particular area to full-screen size for more detailed examination, to perform flaw-amplitude discrimination, and to perform several types of signal filtering to remove flaw indications from any portion of the component. The system also has an isometric display mode that has all the features mentioned above; plus, it provides the amplitude profile in X and Y direction. The system is also capable of performing a flaw-homing routine to determine the flaw orientation.

6.1.1 Initial Inspection Records

The initial real-time inspection record for both the rectangular-and circular-scan modes are the C-scan type. The scan-area display is orientated on the screen to provide a maximum size display. The information pertaining to the inspection, such as, time, data, attenuator setting, type of scan, and part description, are displayed on the bottom of the screen. An example of this type of display is shown in Figure 31, where the indications are for nine flat-bottom holes (FBH's) which are normal to the top surface and for two FBH's and one cut-out which are inclined at 36 degrees and 45 degrees off normal, respectively. The physical description of this test specimen is shown in Figure 32. The two rows of darkened areas which bracket the inclined portion of the specimen are not actual flaws. They are recorded as flaws in the real-time display to ensure actual flaws are not missed when entering or leaving an inclined area. In the inclined area, there are no ultrasonic signals reflected from the back surface of the test specimen. Upon leaving the inclined area and entering the flat

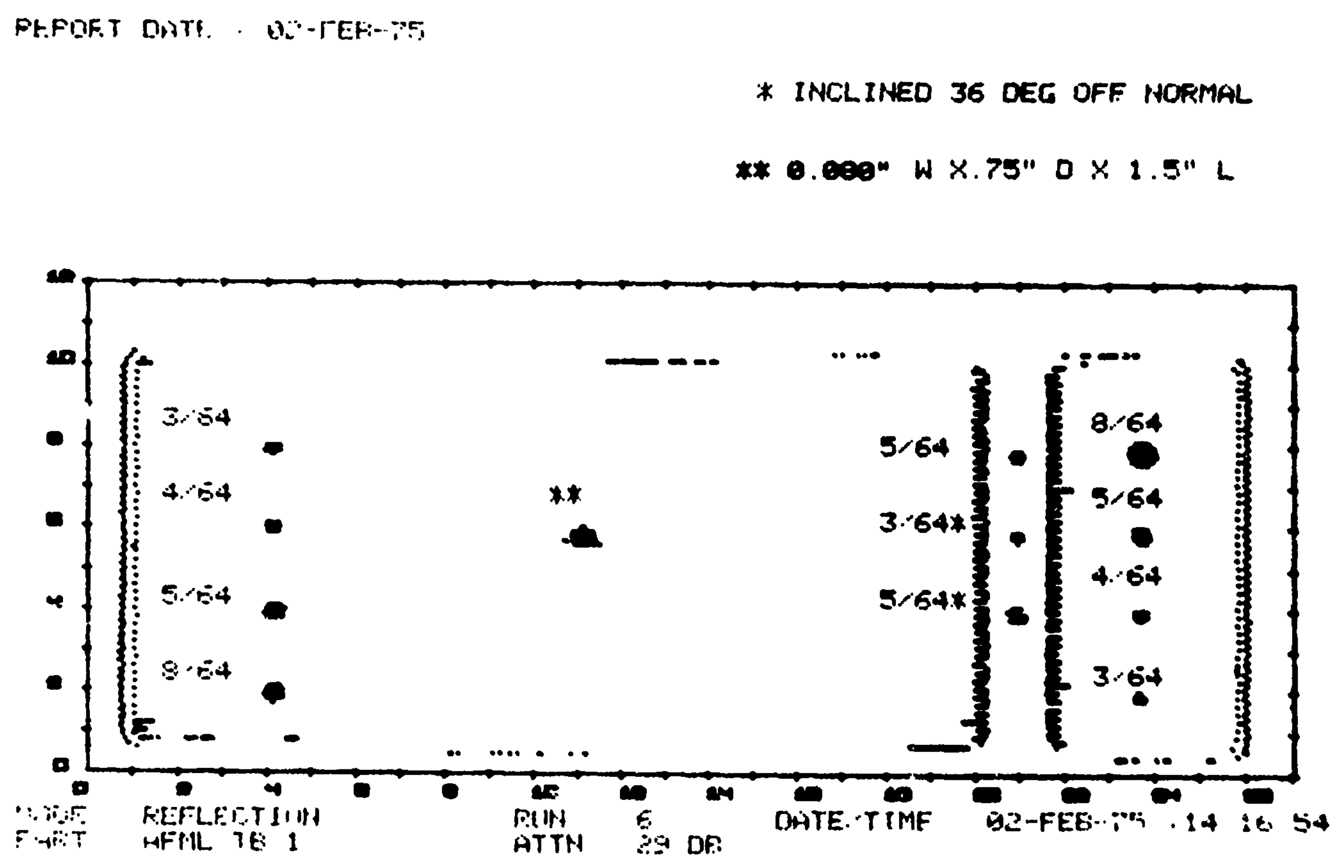


Figure 31. Near-Real Time Inspection Record of AFML TB # 1

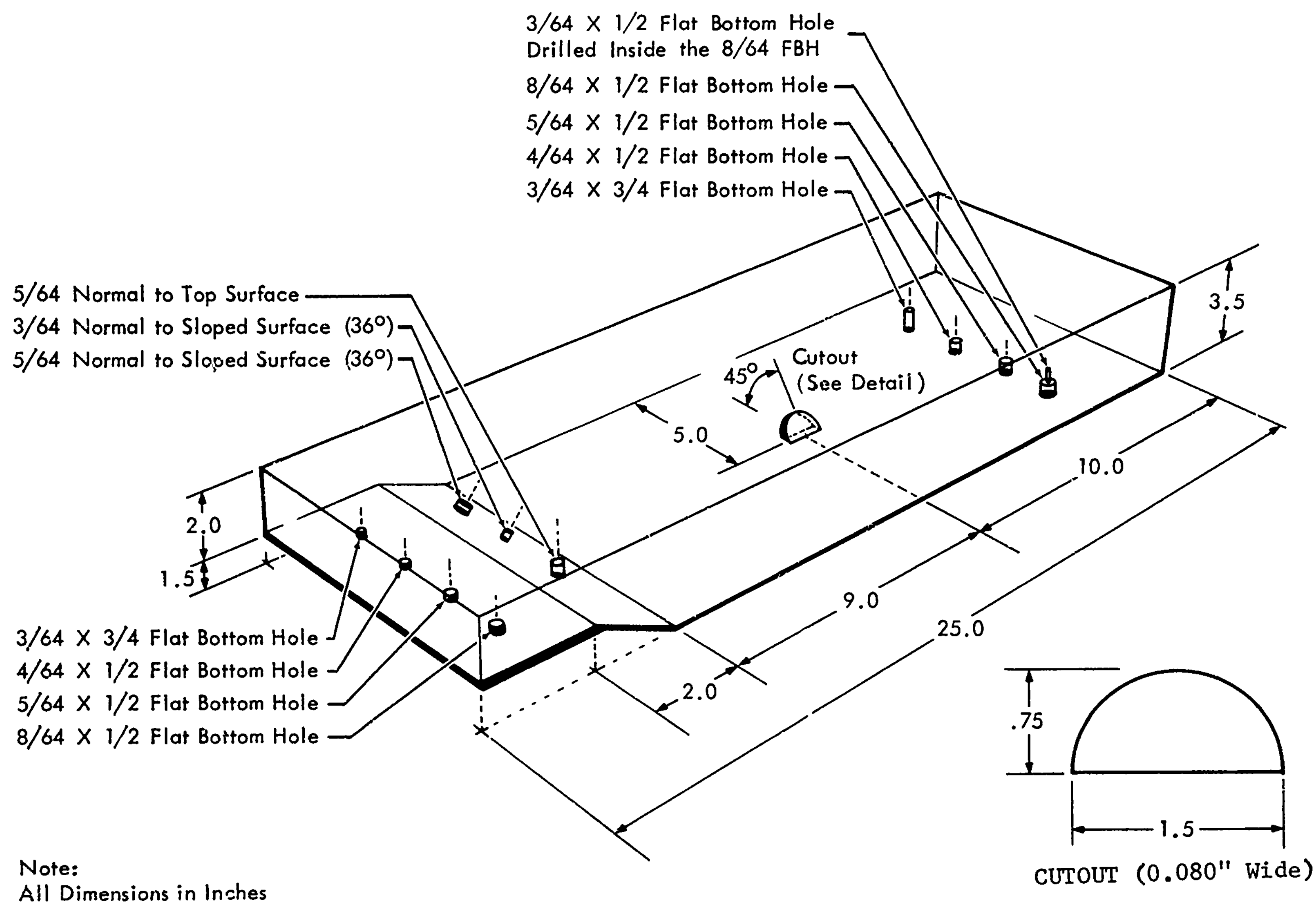


Figure 32. AFML Test Block # 1

area, a back-surface signal will appear. Since the assumption is made that the computer does not know where the boundaries of the inclined areas are, during the real-time inspection signals from the first 0.05 inch of the flat area are recorded as flaws to ensure real flaws are not missed. However, these fictitious flaw indications can be easily removed during the post-inspection signal analysis by the operator knowing the geometry of the test specimen or by the automatic filtering routines, where flaw indications are removed when the flaw depth is identical to the thickness of the test specimen.

Notice that a 3/64- and 4/64-inch FBH inclined about 36 degrees off the normal of the top surface in the inclined area were readily detected as well as the cut-out in the center of the test specimen, which is inclined about 45 degrees off normal.

A typical inspection-report cover sheet, shown in Figure 33, indicates the pertinent inspection information and ultrasonic parameters. This data is part of the permanent inspection results obtained for each scan. A typical post-inspection report data sheet, shown in Figure 34, records the five coordinates, the test specimen thickness, the flaw depth, and flaw amplitude. The maximum flaw amplitude for a 3/64-inch-diameter FBH was calibrated to be a binary number of 4096.

6.1.2 Magnification of Display

The system can magnify or expand a particular area of the test specimen for defect cross-section magnification. Figure 35 shows an enlarged view of a 4/64-inch-diameter FBH which was implanted in the F-111 test Component 1. The other information described in the figure is for signal filtering, which will be discussed in a later subsection. The magnification factor is limited only by the size of the graphics terminal.

6.1.3 Amplitude Discrimination

The system can perform amplitude discrimination, that is, the C-scan recording can be displayed at any sensitivity level less than the initial real-time sensitivity level, which is generally at 25% of the maximum calibrated FBH signal amplitude. Generally, the calibrated FBH signal amplitude is set at 80% of screen height.

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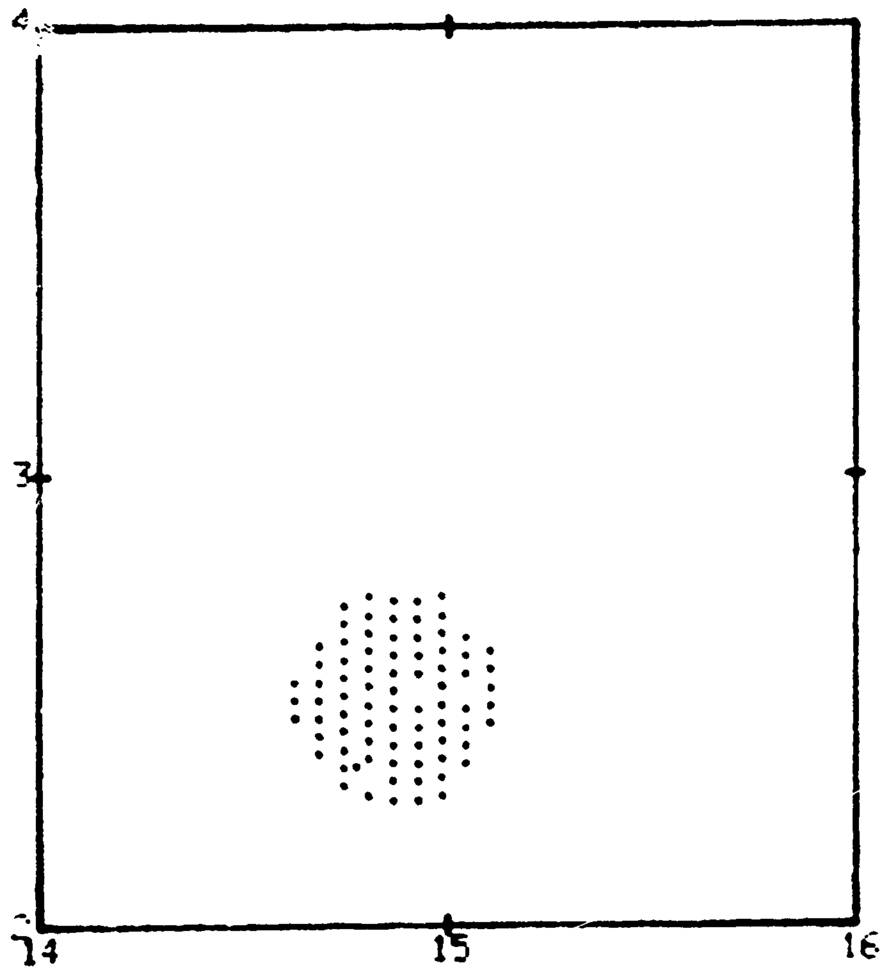
```
REFLECTION MODE DATA REPORT      19-MAR-75    13:18:09     PAGE   1

 RUN INFORMATION

 RUN NUMBER     5                    PART NAME     : AFML TB 1
 DATE         : 02-FEB-75            PART NUMBER   : #1
 START TIME     14 16:54             OPERATOR      : JSK
 STOP TIME    : 14 29 20             TEST SITE     : GD/FW/AML

 CALIBRATION INFORMATION

 MATERIAL THICKNESS    : 3.70 IN.    TEST MATERIAL   : ALUMINUM
 TEST FREQUENCY        :  5.0 MHZ.   TRANSDUCER NO.  : 1003
 ATTENUATOR SETTING    :   29 DB.    REFERENCE STD.  : 5/64 FBH
 FLAW AMPLITUDE @80%   : 3314

 SCAN INFORMATION

 SCAN TYPE        : RECTANGULAR      SCAN LIMITS       : X =  0 00 TO 12.00 IN
 SCAN DIRECTION   : Y                                    Y =  0 00 TO 27 00 IN
 INDEX INCREMENT  :  100 MILS
 SCAN SPEED       :  6.00 IN/SEC

 FILTER LIMITS FOR REPORT

 AMPLITUDES ABOVE :     0            AREA INSIDE       : X =  7.00 TO  8 00 IN
 DEPTHS ABOVE         3.70 IN                            Y =  3.00 TO  5 00 IN
 DEPTHS OUTSIDE       0 00 TO  0.00 IN.
 DEPTHS OUTSIDE   :   0 00 TO  0 00 IN
```

Figure 33. Post-Inspection Report Cover Sheet

REFLECTION MODE DATA REPORT   19-MAR-75   13 18:09   PAGE 2

X	Y	Z	ROTATE	TILT	THICK	DEPTH	AMPLT	FS/BS GATE
7.80	4.09	-0.03	0.0	0.0	3.49	2.54	62	
7.80	4.10	-0.02	0.0	0.0	3.49	2.55	148	
7.80	4.11	-0.02	0.0	0.0	3.49	2.54	199	
7.80	4.12	-0.02	0.0	0.0	3.49	2.55	245	
7.80	4.13	-0.02	0.0	0.0	3.49	2.54	243	
7.80	4.15	-0.02	0.0	0.0	3.49	2.55	227	
7.80	4.16	-0.02	0.0	0.0	3.49	2.54	177	
7.80	4.17	-0.02	0.0	0.0	3.49	2.55	123	
7.90	4.25	0.03	0.0	0.0	3.49	2.54	163	
7.90	4.24	0.03	0.0	0.0	3.49	2.54	354	
7.90	4.23	0.03	0.0	0.0	3.49	2.54	543	
7.90	4.22	0.03	0.0	0.0	3.49	2.54	732	
7.90	4.20	0.03	0.0	0.0	3.49	2.54	959	
7.90	4.19	0.03	0.0	0.0	3.49	2.53	1104	
7.90	4.18	0.03	0.0	0.0	3.49	2.54	1284	
7.90	4.17	0.03	0.0	0.0	3.49	2.54	1454	
7.90	4.16	0.03	0.0	0.0	3.49	2.54	1547	
7.90	4.14	0.03	0.0	0.0	3.49	2.54	1613	
7.90	4.13	0.03	0.0	0.0	3.49	2.54	1630	
7.90	4.12	0.03	0.0	0.0	3.49	2.53	1628	
7.90	4.11	0.03	0.0	0.0	3.49	2.53	1562	
7.90	4.09	0.03	0.0	0.0	3.47	2.54	1476	
7.90	4.08	0.03	0.0	0.0	3.49	2.54	1373	
7.90	4.07	0.03	0.0	0.0	3.49	2.54	1229	
7.90	4.06	0.03	0.0	0.0	3.49	2.54	1141	
7.90	4.05	0.03	0.0	0.0	3.49	2.53	1012	
7.90	4.03	0.03	0.0	0.0	3.49	2.53	891	
7.90	4.02	0.03	0.0	0.0	3.49	2.53	776	
7.90	4.01	0.03	0.0	0.0	3.49	2.54	681	
7.90	4.00	0.03	0.0	0.0	3.49	2.53	578	
7.90	3.98	0.03	0.0	0.0	3.49	2.53	466	
7.90	3.97	0.03	0.0	0.0	3.49	2.54	393	

Figure 34. Post-Inspection Typical Report Data Sheet



PART F-111 COMPONENT #1 RUN 6
DATE/TIME: 30-JAN-78,06:38:56
CONSECUTIVE PULSES INCLUDED FROM 3 TO 14
ADJACENT SCAN LINE FILTER

FIGURE 35. Magnification 4/64" FBH

Figure 36 shows four C-scan displays of an 8/64-inch-diameter FBH at 20%, 40%, 52%, and 56% of screen height. At 56% of screen height, the C-scan display area is equal to the actual cross-sectional area of the FBH.

The amplitude-discrimination technique can be very useful in displaying the actual cross-sectional area of a defect. Thus, it can be used in providing a quantitative means of defect rejection or acceptance automatically and without operator interpretation or intervention.

6.1.4 Isometric Display

Isometric display was developed to aid in visualizing flaw size and shape. It displays the amplitude profile over a potential flaw area. The conventional C-scan recording describes a potential flaw area with a fixed but selectable amplitude level. The isometric display presents the maximum amplitude above a threshold level over a potential flaw area. An isometric display of an 8/64-, 4/64-, and 3/64-inch diameter FBH is shown in Figure 37. This display technique is not a three dimensional display of a flaw, but a three-dimensional display of flaw amplitude. Amplitude discrimination and other post-signal processing techniques can also be applied to the isometric display as well as to the conventional C-scan presentation.

6.2 Ultrasonic Spectroscopy

Ultrasonic spectroscopy refers to the use of destructive as well as constructive interference of ultrasonic waves in resonating elements (cavities) to characterize flaws and material properties. Resonance dips (destructive interference) and resonance peaks (constructive interference) are easily observed in the frequency domain when the acoustic waves are Fourier transformed from the time domain. The correlation of these frequency dips or peaks can yield the dimensions of defects and/or material properties.

There has been a tremendous amount of research and developmental work directed at the application of ultrasonic spectroscopy to materials and flaw characterization. The list of references can be several pages long; thus, no attempts will be made to reference all the pertinent papers in this write-up. However, a broad discussion in the subject matter can be found in "Applications of Ultrasonic Interference Spectroscopy to Materials and Flaw

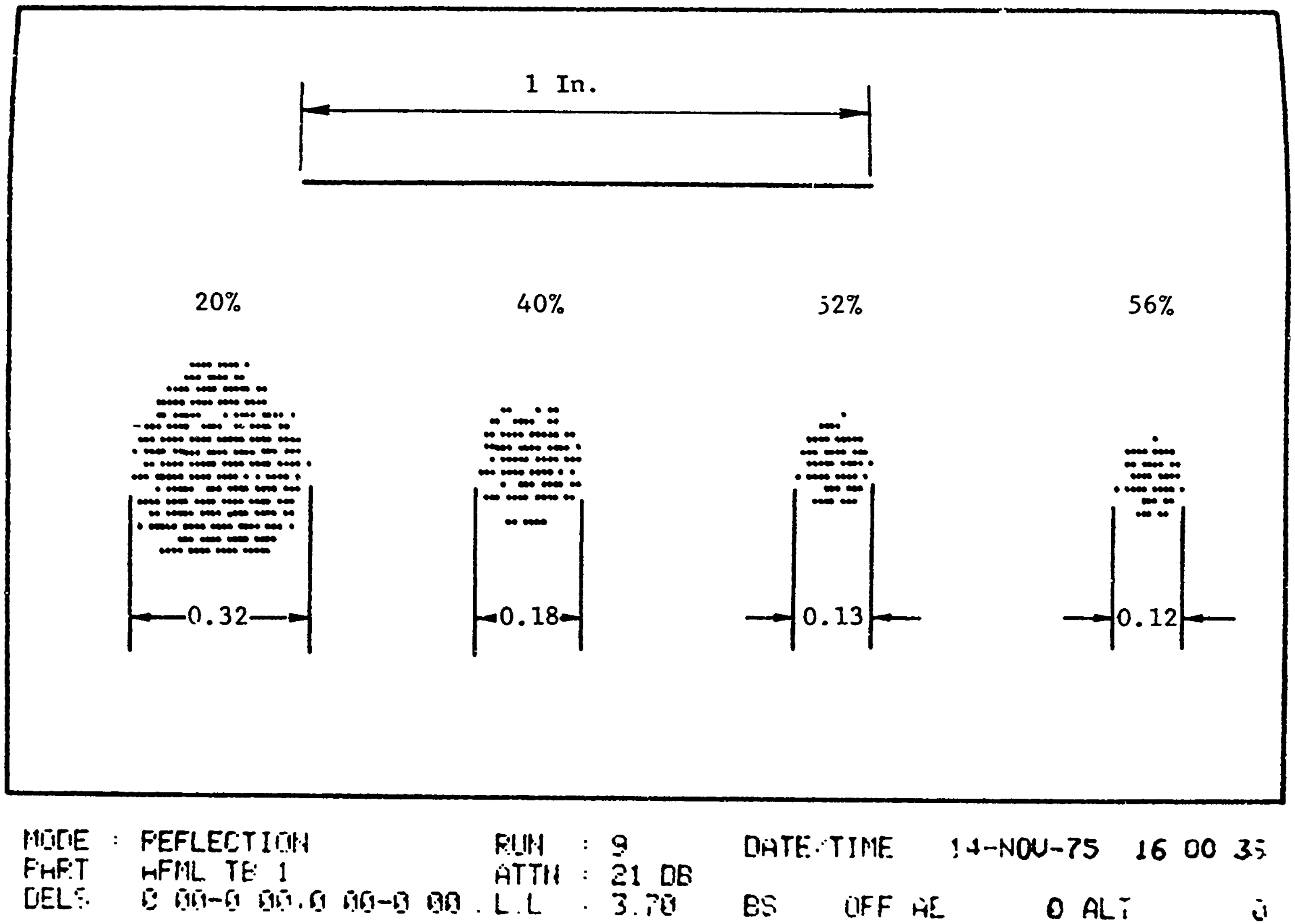


Figure 36. Comparison of Flaw Size Indications at Different Triggering Levels for 8/64 FBH

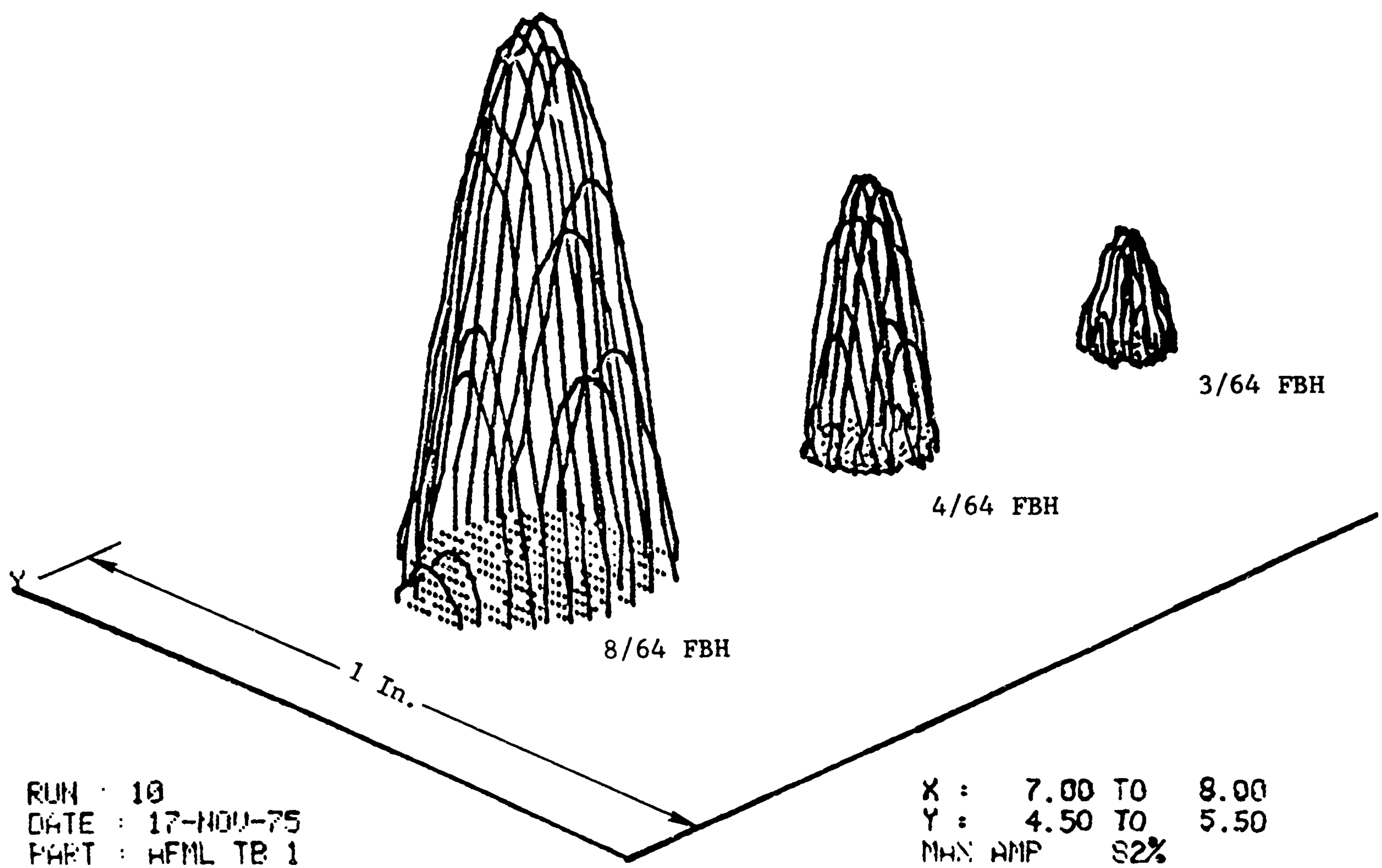


Figure 37, Isometric Amplitude Profiles from Three Flat-Bottom Holes

Characterization" (Ref. 11) and a specific application to adhesive bonds can be found in "Principles and Applications of Ultrasonic Spectroscopy in NDE of Adhesive Bonds" (Ref.12).

RF Waveform Digitizer

To conduct ultrasonic spectroscopy, the RF waveform of the ultrasonic signal must be digitized. Figure 38 is a block diagram of the equipment used to digitize the RF waveform. The equipment consists of (1) an oscilloscope (Tektronix Type 555), (2) a scanning scope (HP 175A with 1726A plug in), (3) a digital computer (Digital Data Corporation PDP 11/45), (4) a digital-to-analog converter (PDP 11/45 D/AC interface), (5) an analog-to-digital converter (PDO 11/45 A/DC interface), (6) a memory scope (Tektronix Model 4010), and (7) a hard copier (Tektronix Model 4610).

The digitization system works as follows:

1) A segment of an RF waveform that is displayed on the oscilloscope is delay mode displayed on the scanning scope.

2) The delayed RF display on the scanning scope is sampled at either 256, 512, or 1024 sequential positions along the time axis by a computed analog voltage which is fed to the 1726A input of the sampling scope through the D/A converter.

3) The analog vertical output of the 1726A is converted to digital data and stored in the computer memory at each sequential time.

Signal Processing

Once stored in the computer, the digitized RF can be Fourier transformed by digital computer software. Both the digitized RF and the resulting Fourier transform can be displayed on the memory scope and (if desirable) can be hard copied. The total time required to perform the calculation and display the frequency spectrum is normally about eight seconds when 256 data points are digitized, Fourier transformed, and displayed at 200 frequency points.

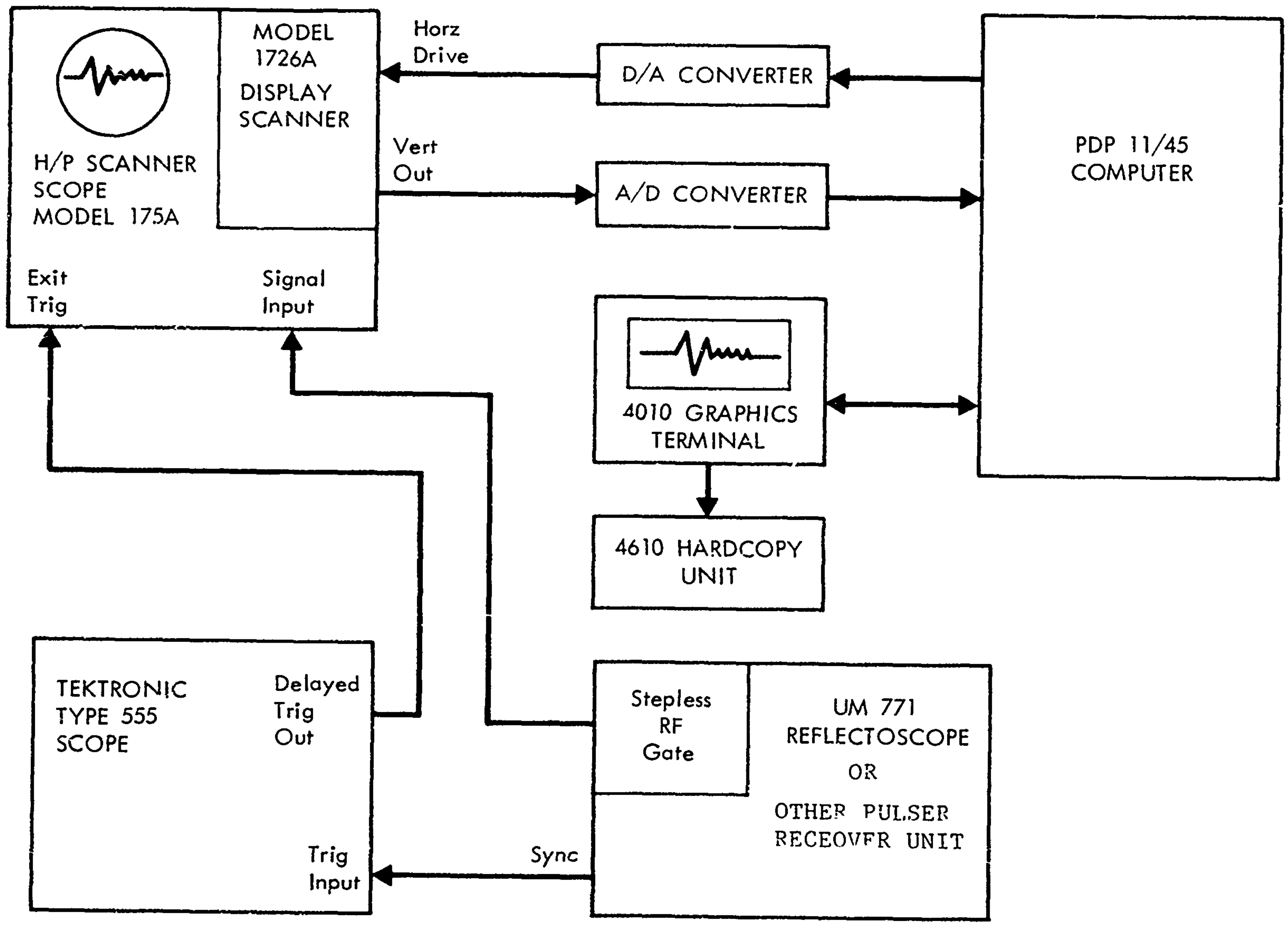


Figure 38. Block Diagram of the RF Digitizer Set-Up

Fourier Transform Software: Data taken in the time doman are related to the frequency spectrum by the well-known relationship.

$$F(t) = \frac{1}{2\pi} \int G(\omega) e^{i\omega t} \, d\omega \qquad (1)$$

The frequency spectrum G (ω) can be obtained from the integral

$$G(\omega) = \frac{1}{2\pi} \int F(t) e^{-i\omega t} \, dt \qquad (2)$$

The term Fourier transform refers to obtaining $G(\omega)$ from $F(t)$, which can be done with a frequency analyzer or by direct integration of equation (2). The Fourier transform of $F(t)$ that was used in this study was analytical. The waveform $F(t)$ was digitized as 256 values with equal time spacing within a sampling gate T seconds long. A quadratic fit of the form $F(t) = A+Bt+Ct^2$ was used to interpolate between successive values of $F(t)$. The resultant frequency spectrum $G(\omega)$ is a product of the source spectrum $S(\omega)$ and the reference spectrum $R(\omega)$, where $R(\omega)$ is the transducer and electronic component frequency response. It is highly desirable to remove this unwanted modulation in nondestructive testing, so the dependence on transducer and electronic component response will be minimized. This undesirable modulation is removed by dividing the resultant spectrum $G(\omega)$ by the reference spectrum $R(\omega)$, or $S(\omega) = G(\omega)/R(\omega)$.

The dimensions of the resonating elements are obtained simply from the frequency spacing between the interference dips or peaks. The condition for resonance to occur is for the resonating element to have dimensions that are integral multiple half-wavelengths of sound. The condition for resonance is

$$t = \frac{n\lambda}{2\cos\theta} \qquad (n = 1, 2, \ldots) \qquad (3)$$

where t is the dimension of the resonator, n is an integer, λ is the wavelength of sound in the resonator, and θ is the angle between the direction of sound propagation in the resonator and the normal to the surface of the resonator. For normal incidence, the angle θ is zero.

Flaw and Material Characteristic Determination: Ultrasonic spectroscopy can be applied to determine:

1) Material or plate thickness
2) Discontinuity or gap width
3) Velocity of sound
4) Adhesive bondline thickness
5) Disbond gap width in bonded assemblies

Parallel gap openings ranging from a mil to several mils and filled with a liquid can be measured with ultrasonic spectroscopy. The lower limit of the gap opening which can be determined is the highest operating frequency that can be propagated through the material. The gap opening can be determined from either compressional or shear waves. Figure 39 shows the frequency spectra of the reference along with the spectra of slots having dimensions of 0.023-in. width by 0.20-in. depth and 0.043-in. width by 0.20-in. depth cut into a 0.50-in thick Al plate. Both slots were filled with water. The frequency spectra were obtained for 45^{o} shear waves in the reflection mode. The slot width can be obtained by using the equation shown in the bottom left-hand corner of the figure by solving for t and obtaining F from adjacent frequency minima. The velocity of sound in the gap material is C and the velocity of sound in the metal is b. The gap width obtained agreed to within 2% of the actual slot width. Fill media such as glycerin, air, and mercury have been studied with comparable results. Waterfilled gaps a few mils wide have easily been measured through 8 inches of metal travel (4 inches each way) by using a compressional wave at normal incidence.

The procedures for measuring slot width have also been successfully applied to measuring the diameter of a right cylinder. In all cases the velocity of sound in the slot has to be known or assumed in order to determine the dimension. The converse that knowledge of the dimensions allows one to compute ultrasonic velocities, is also true.

6.3 Random Flaw Detection

Flaw homing is a technique developed to detect randomly-oriented flaws and determine flaw orientations. During post inspection analysis, a software routine automatically returns the transducer to areas having flaw indications and sudden loss of bottom surface reflections and performs a search routine. The search routine consists

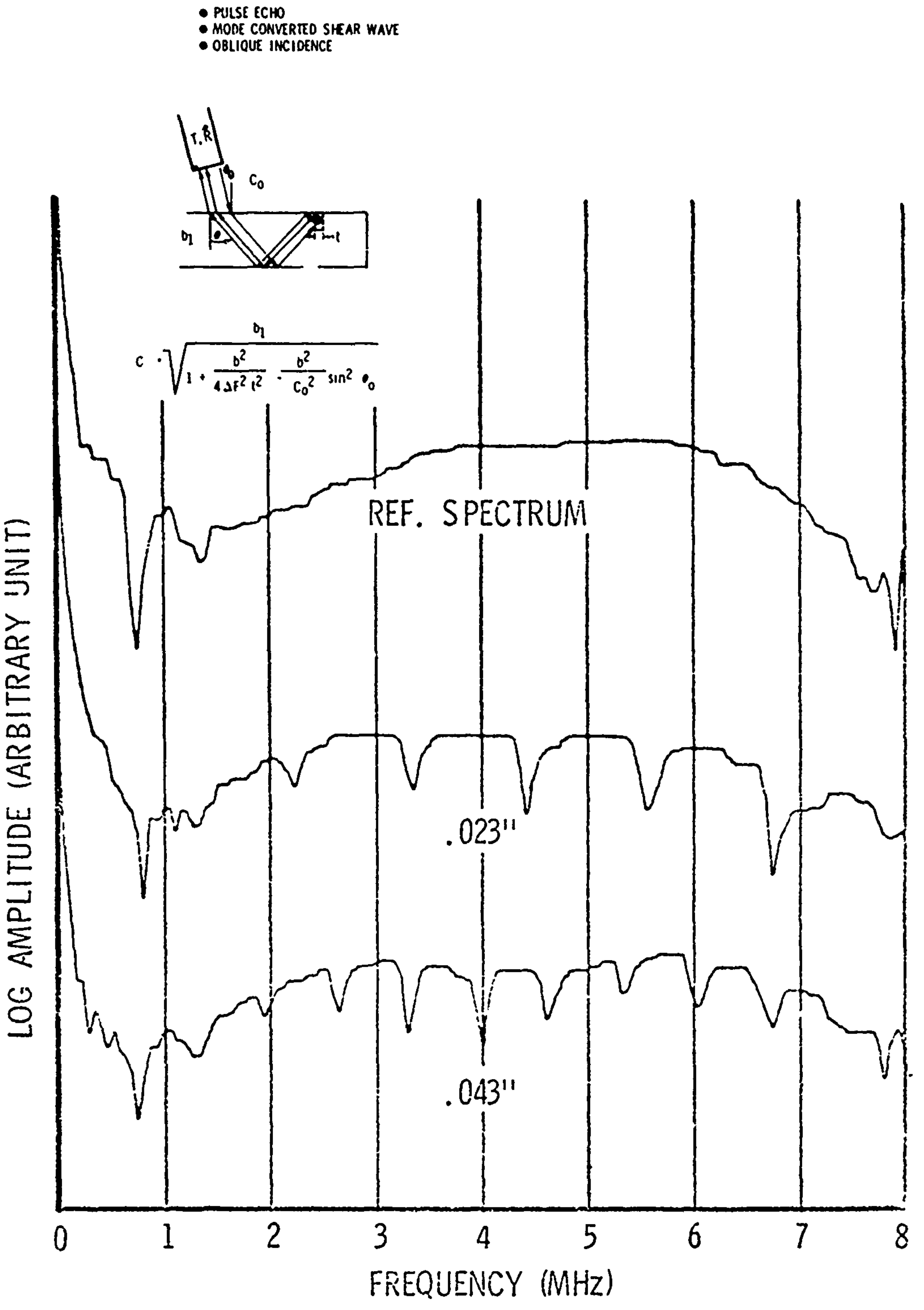


Figure 39. Shear Waves Frequency Spectra for 0.023 in. and 0.043 in. Slots.

of scanning the transducer over the suspected area with many possible directions of sound entry to the test specimen and recording the coordinates of the transducer where maximum reflected amplitude is obtained. The display over a 45° inclined slot in the AFML Test Block No. 1 is shown in the center portion of Figure 32. Interpretation of this display is difficult, but the coordinates where the maximum amplitude was obtained is recorded at the bottom of the display.

<u>Search for Inclined Flaw (SFIF)</u>: This routine performs a preprogrammed search. The search pattern is similar to the one depicted on Figure 40. The variables which can be input are radius, delta, Alpha 1 and Alpha 2.

The search is performed as follows: The scanner is driven to each numbered point, and at this point the TILT is driven from Alpha 1 to Alpha 2; the computer stores the maximum amplitude and the number of times a flaw signal is detected; the scanner is then moved to the next point, and the process is repeated. The numbers indicate the scan sequence.

In order to obtain the coordinates at which the optimum incident angle occurs, a number (N) is formed from the maximum amplitude and the number of detections during that radial scan. The radial scan is selected on the basis of the largest value of N; the point along that radius is determined on the basis of the maximum amplitude.

N = 3 * NN * K + Max. Amp.

K = 4-96/(Maximum number of possible detection)

NN = Number of detections

Max Amp = Maximum amplitude

The value of N ranges from 0 to 16383.

<u>Flaw Homing</u>: The search for an inclined flaw was performed on the large elox slot in AFML Test Block No. 1 during post inspection analysis. The scan pattern as described in the previous paragraph was executed, and maximum aplitude was obtained at a tilt angle of -9.9° at an X

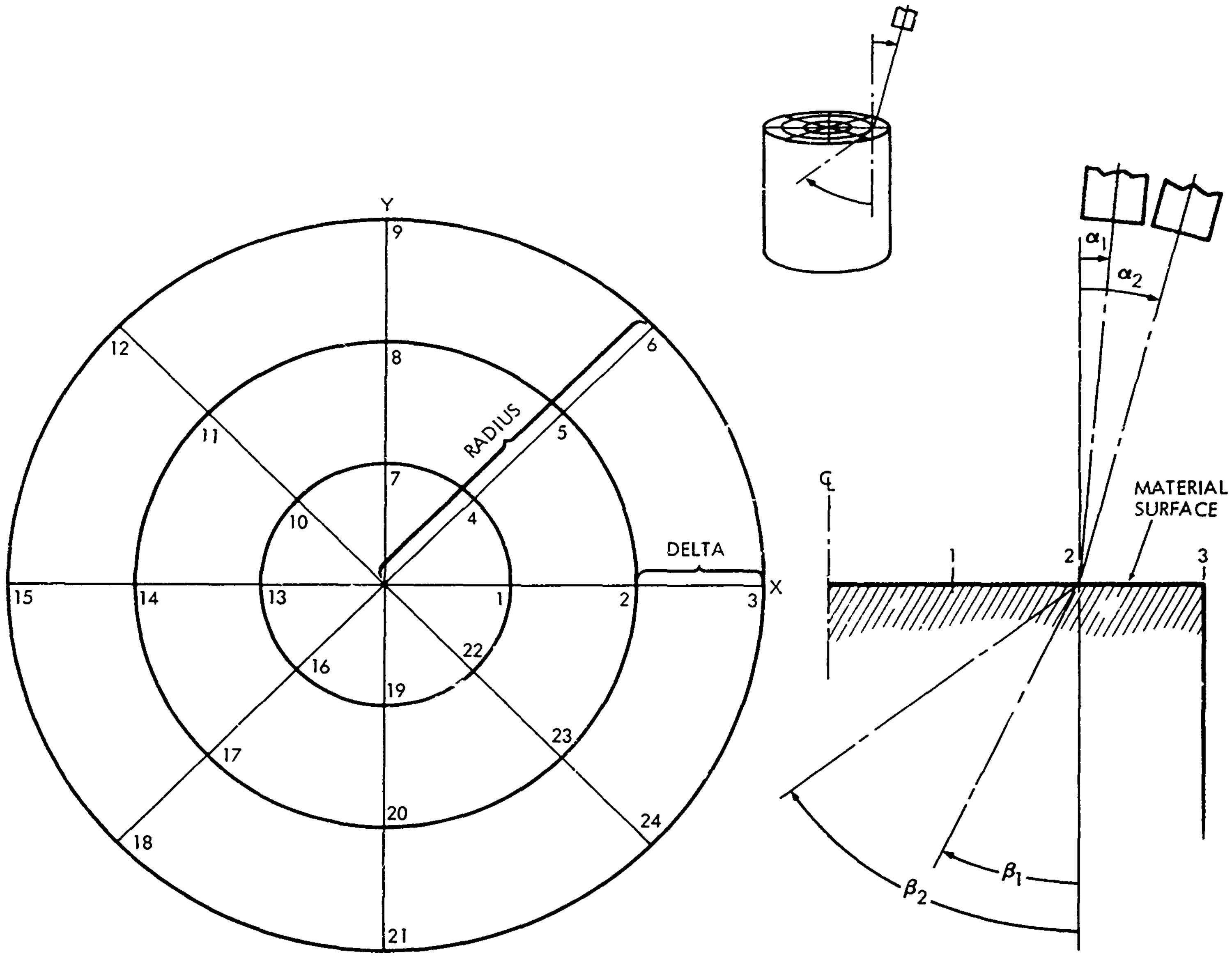


Figure 40. Flaw Homing Search Pattern

position of 5.0 and Y position of 10.0 for the 45^{o} inclined slot. Using this angle of -9.9^{o}, a scan was made over the suspected area. The results of this scan are shown in Figure 41. The value of flaw homing is demonstrated by comparing the results obtained with the scan at the preferred angle (shown in Figure 41) with the expanded display of the results obtained with a scan at normal incident (shown in Figure 42), which is the same as the center flaw indication shown in Figure 31.

6.4 Signal Filtering

Signal filtering was designed to increase the signal-to-noise ratio and to remove the ambiguities from the ultrasonic C-scan presentation to display only flaw data. The spatial filter, which was developed in the previous AFML contract, the consecutive-points filter, and the adjacent-scan-line filter were developed to achieve these objectives.

Spatial Filter: A spatial-filtering technique was developed for use in examining the inspection results in more detail. This technique enables flaw indications existing in any portion of the test specimen under inspection to be deleted from the C-scan display. Since the computer records the coordinates (X, Y, Z, θ and Ø) and the depth of the flaw indications, deletion of flaw indications from any portion of the test specimen can be accomplished by simple computer instructions. Flaw indications from surface irregularities, edges, etc., can be filtered from the display. Spatial filtering can be developed to fit the final or net shape of a component to a rough forging that contains flaws. Applications and usefulness of spatial filtering to aid in removing ultrasonic ambiguities can be seen by comparing the C-scan recordings of Figures 43 and 44. Figure 43 is the C-scan recording of the F-111 Landing Gear Al forging, shown in Figure 1 without any spatial filtering. Figure 44 is the same C-scan recording but with spatial filtering applied, that is, signals originating from the forging that is between 0.7 to 0.85 inch and below 1.45 inches from the top surface of the forging are removed. Signals from these areas come primarily from surface irregularities at the flanges and back surface of the forging. As can be seen by comparing the C-scan presentations in these two figures, spatial filtering removed some of the ambiguities and improved the clarity of the presentation. Note that both 3/64- and 4/64-inch-diameter FBH's drilled at an angle of 30^{o} off normal and located in a radius were detected.

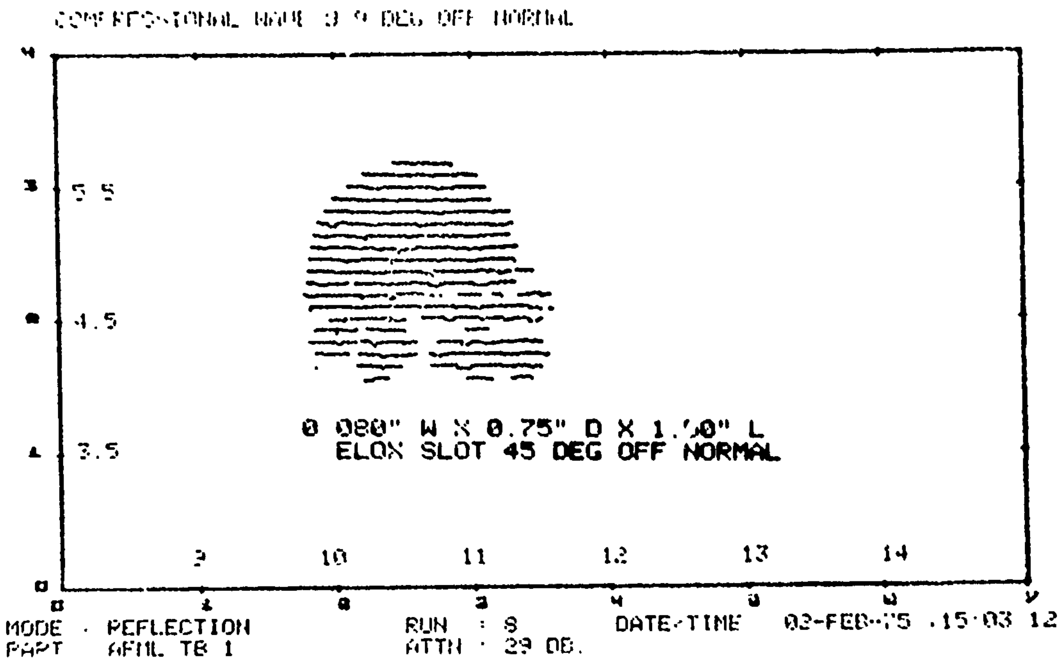


Figure 41. Near-Real Time Inspection Record of Inclined Flaw at -9.9^{o} Tilt Angle

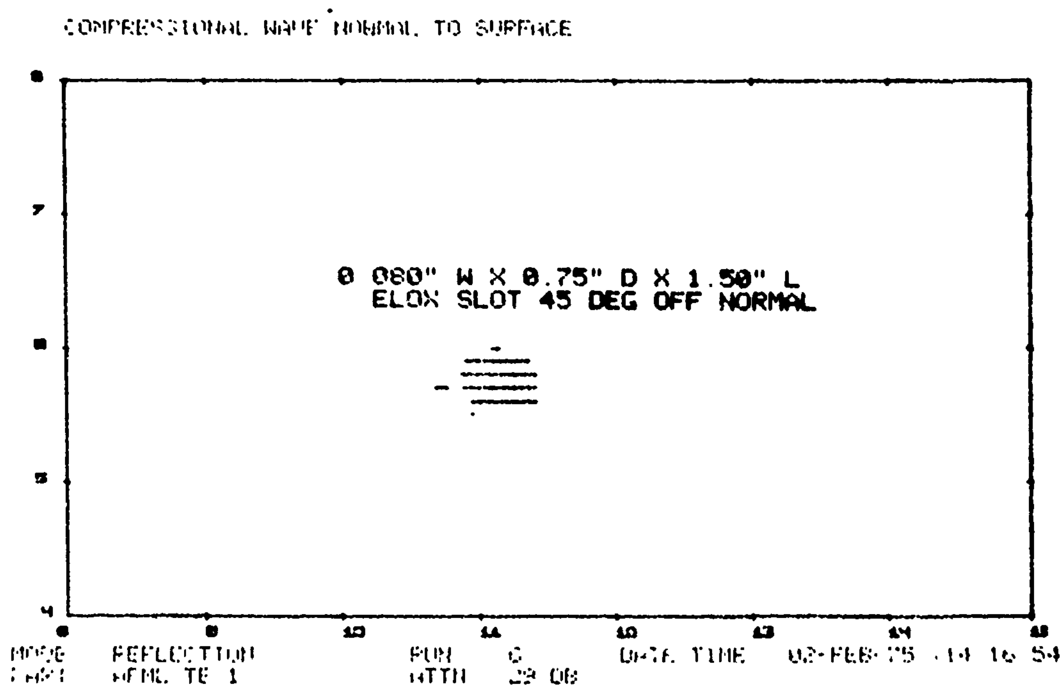


Figure 42. Post-Inspection Expansion of Normal Incident Wave of Inclined Flaw

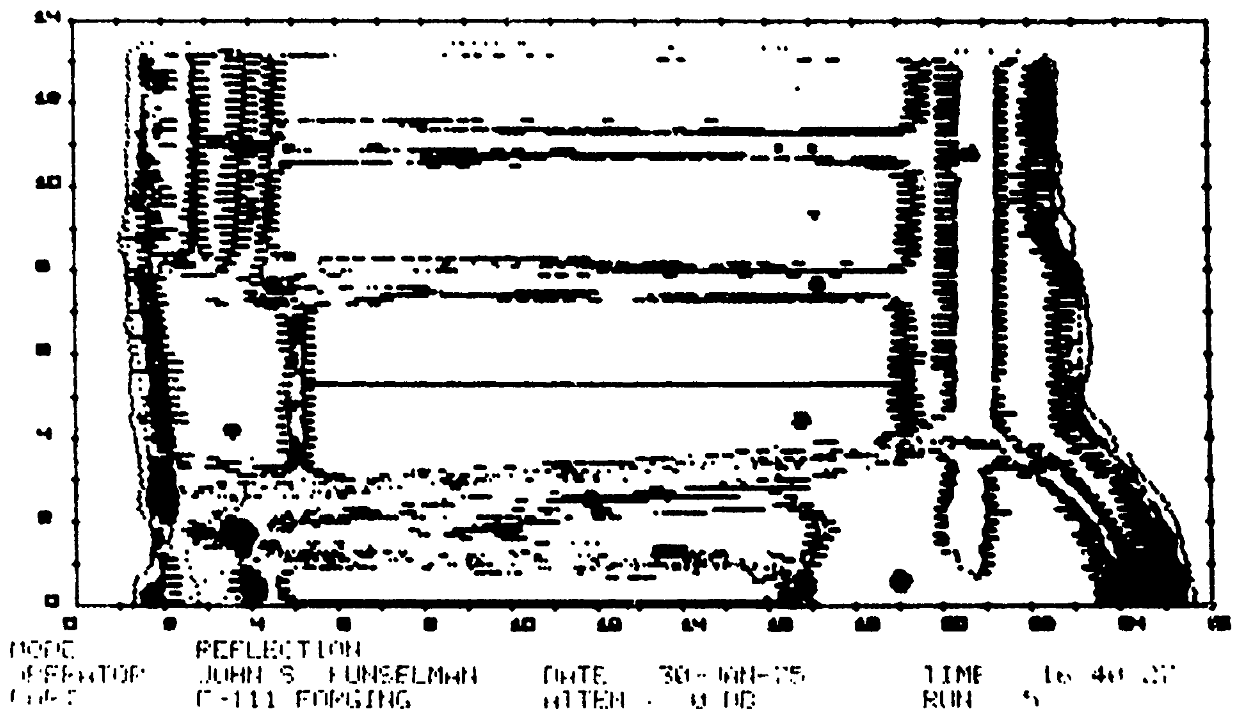


Figure 43. Near-Real Inspection Record for the Compressional Scan of F-111 Aluminum Forging

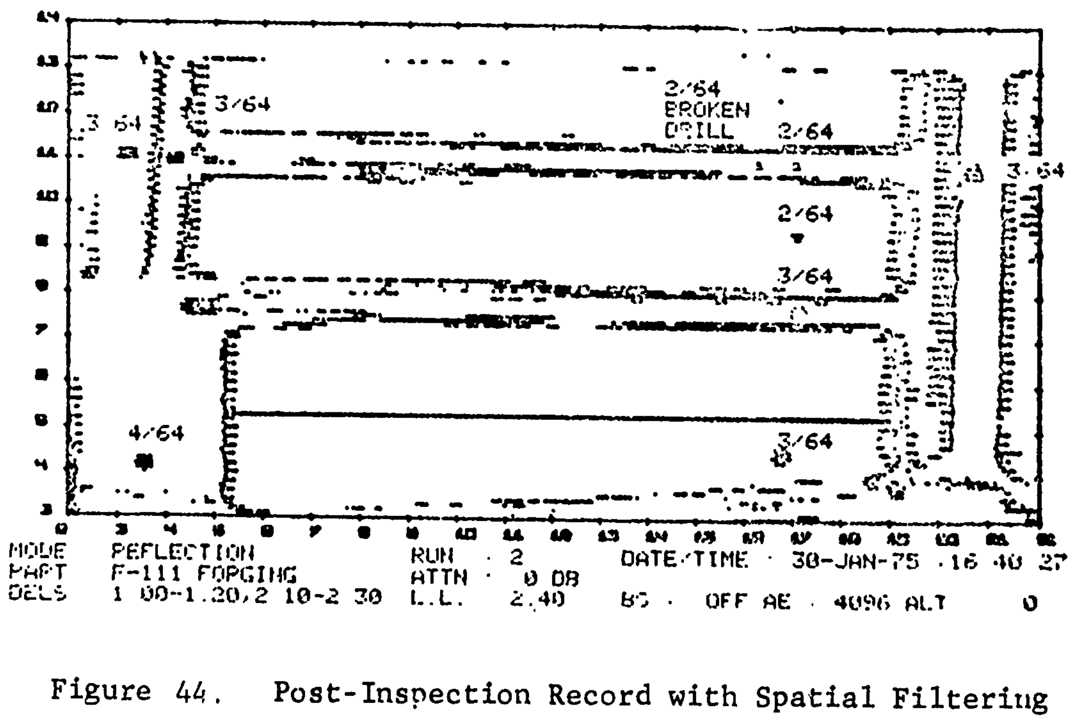


Figure 44. Post-Inspection Record with Spatial Filtering

If the final ne' dimensions of a complex forging are known, a filtering scheme can probably be designed to remove nearly all ambiguous signals outside the final dimensions of the forging.

Consecutive-Pulse Filter (CPF): To aid in removing ambiguous ultrasonic flaw data from the display, a consecutive-point filter was developed and can be used by the operator during post-inspection data analysis. This filter was designed to remove random signals occurring within the flaw gate which could be caused by transient electronic signals, abnormal grain sizes, etc. The consecutive pulse filter will discriminate against both consecutive pulses less than a specified minimum and consecutive pulses greater than a specified maximum. The minimum and maximum selected for the consecutive pulse filter are optional integer variables and must be input to the computer through the teletype. It is also a requirement that the consecutive pulses be from the same depth. The selection of the minimum number of consecutive pulses is dependent on the minimum flaw size which needs to be detected, the cleanliness of the material being inspected, etc. For the aluminum components and inspection speed of the program, two to four consecutive pulses were selected as the minimum number. To discriminate against geometry-related signals from a component such as back-surface radii, holes, etc., a maximum number of pulses can also be selected to remove false flaw signals. Figure 45 shows a display of a selected area taken from Component I in which the consecutive-pulse and amplitude-profile filters were applied. This selected area contained three FBH's, as indicated in the figure. However, as can be seen, there are still spurious signals present even with the application of these filter routines.

Adjacent-Scan-Line Filter (ASLF): After viewing Figure 45, it is obvious that some other filtering routines are needed to remove the existing non-flaw signals. In line with the consecutive-pulse filter, the ASLF was developed to remove signals from the display as flaw signals unless the signals appeared from adjacent scan lines. It was assumed that to detect flaws of the size equivalent to a 3/64-inch-diameter FBH in most airframe components using typical inspection procedures (1/2-inch-diameter transducer, 0.05-inch index, etc.), flaw signals will be received from adjacent scan lines. Using the ASLF in conjunction

POST PROCESSING

CONSECUTIVE PULSES FROM 4 TO 14 IN
CONJUNCTION WITH AMPLITUDE PROFILE
CONSECUTIVE PULSES WITH AMPLITUDE
LEVEL = 1 OMITTED

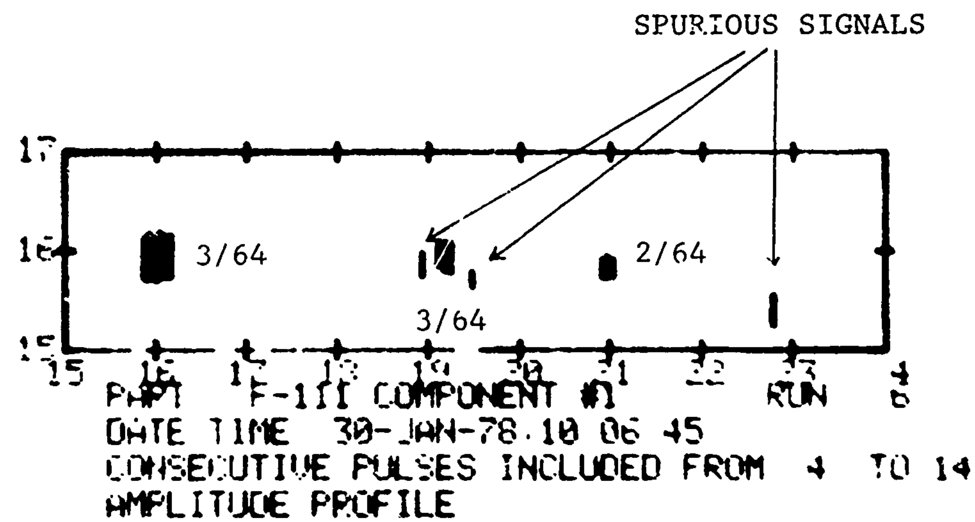


FIGURE 45. Section of Component I Using Consecutive Pulse Filter and Amplitude Profile

with the CPF as well as the amplitude-profile routine, Figure 46 showed that the spurious signals as indicated in Figure 45 have been eliminated and only flaw data are displayed. As can be seen in Figure 46, a 2/64-inch-diameter FBH was detected with flaw signals appearing in three adjacent scans, and a 3/64-inch-diameter FBH located in a rib was also detected with flaw signals appearing in three adjacent scans.

POST PROCESSING

<u>CONSECUTIVE PULSES</u> FROM 4 TO 14 IN
<u>CONJUNCTION WITH AMPLITUDE PROFILE</u>
<u>AND ADJACENT LINE FILTER</u>
CONSECUTIVE PULSES WITH AMPLITUDE
LEVEL = 1 OMITTED

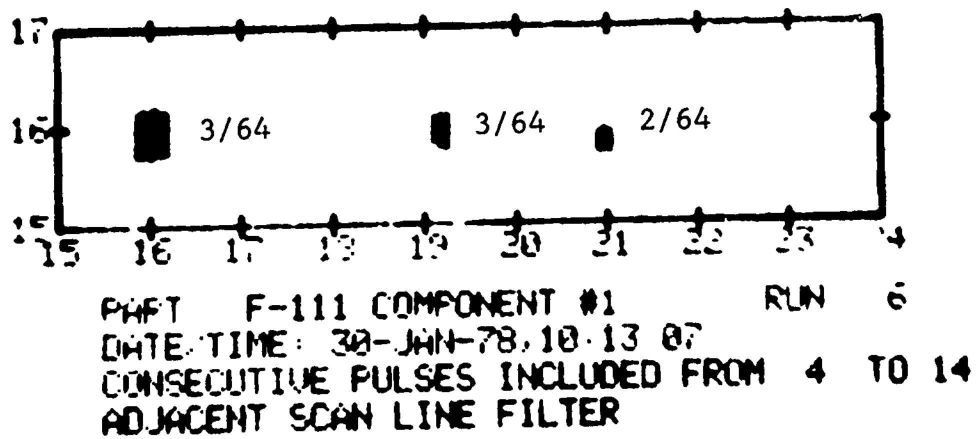


FIGURE 46. Section of Component I Using Adjacent Scan Line Filter

SECTION VII

COMPONENT DEMONSTRATION

The ability of the optimized CAUIS to successfully inspect the three selected complex airframe component and to achieve the objectives of this program is discussed in this section. The three selected demonstration components were described in Section III of this report. However, due to a contract modification, efforts to inspect Component II were deleted. This component was one of the F-16 Wing Attach Fittings, which were designed by the computer-aided design (CAD) approach. The complete geometrics of this component are described by mathematical equations which are stored in a digital computer. The approach taken by this present contract was to input these mathematical equations into the CAUIS computer for contour following and inspection of the component. The software to implement this inspection approach was developed by Pattern Analysis and Recognition Corporation as a subcontract to this program. However, it was not implemented due to the contract modification. The software and methodology for this approach were developed by PAR and is described in Reference 10.

7.1 Ultrasonic Zone Scanning of Component I

The ultrasonic zone scanning of Component I, the F-111 landing-gear forging, was performed with the ribbed side of the forging resting on the back-up plate over a square area measuring 26 inches. The time necessary to scan Component I took approximately two hours to complete. The post-processing time may vary with the amount of data and the level of flaw clarity desired.

7.1.1 Zone Scans Results

Component I, with a somewhat simpler geometry than Component III, requires a Zone Ø scan, three Zone N scans, several vector radius scans, and a circular radius scan for completion of the scanning process. The Zone Ø scan, which defines the boundaries and identifies the orientation of the part to the computer, is shown in Figure 26 for Side 1 and Figure 27 for Side 2. Figure 47 shows a Zone Ø scan of Component I with the display format used in the Tektronix memory scope for flaw data display. The left-hand

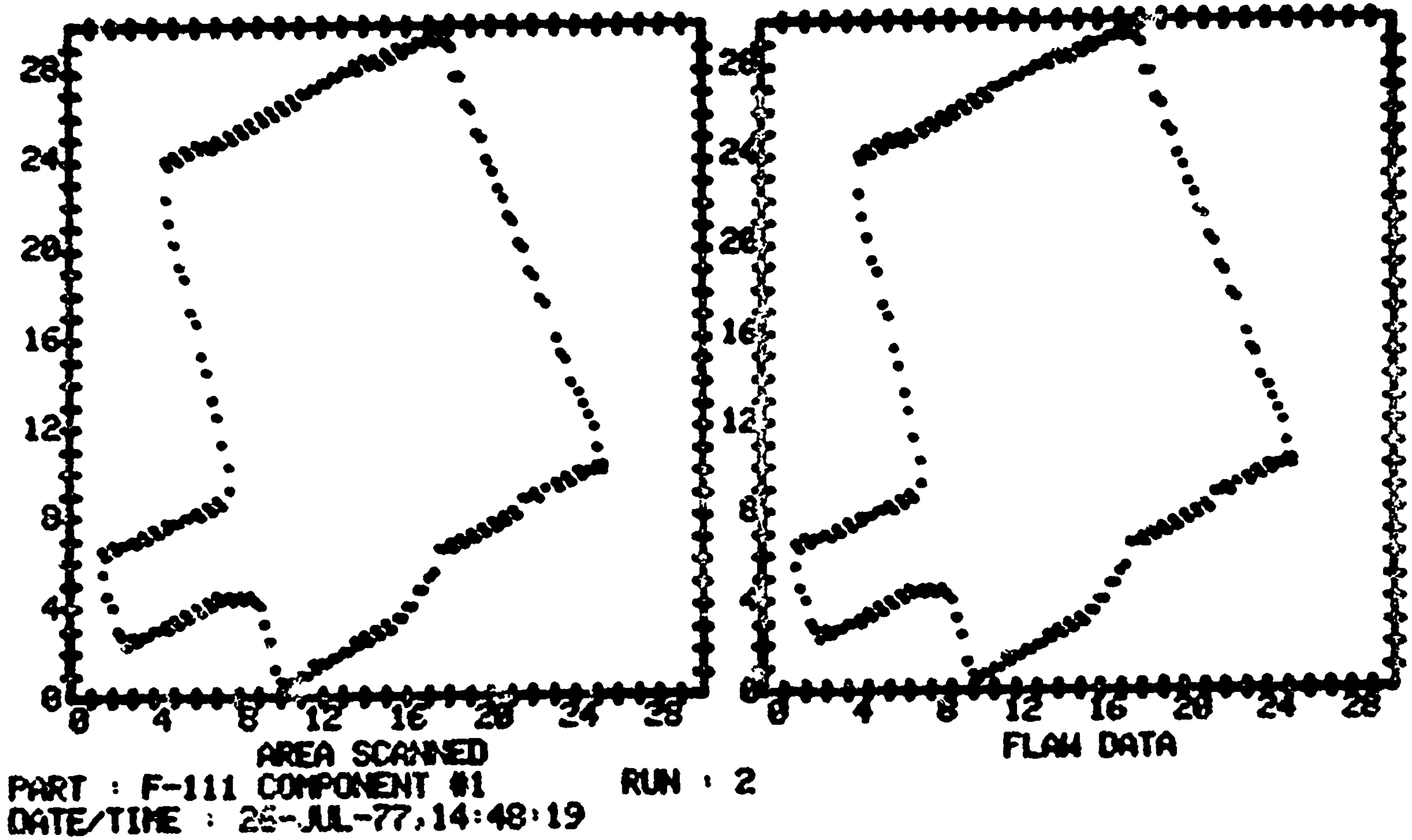


FIGURE 47. Zone 0 Scan Results

side of the display shows the area scanned. The right hand side is for the display of flaw data within the boundary of the component under inspection.

In addition to Zone N scans, vector-fillet-radii, curved-fillet-radii and pocket scanning,capabilities were developed to provide for complete inspection of complex components. Figure 48 illustrates the results of three vector-fillet-radii scans of Component I. Figure 48a shows the radii scanned and Figure 48b shows that no defects were detected.

A Zone 1 scan of Component I can inspect up to 80% of the volume for defects whose plane is parallel to the surface of the component. A Zone 2 scan adds another 5% of the volume inspected. Thus two zone scans can inspect up to 85% of the component for flaws with planes parallel to the surface of the component. Table 5 gives the estimated volume scanned with just two zone scans for Components I, II, and III. Figure 49 shows all the potential-flaw data from the zone scans of Component I. As can be seen from this figure, the flaw data from the FBH's are totally masked by the geometry-related signals which appeared within the flaw gate.

7.1.2 Post-Inspection-Signal Processing

As expected, the real-time data display of the zone scans is of little practical use for flaw identification, and post inspection signal processing must be applied to eliminate the spurious data from the display. The application of spatial filtering to Component I removed large amounts of the non-flaw data from the display. However, as is discussed in TR-75-82 and briefly rediscussed in Section VI (Figures 43 and 44) of this report, considerable amounts of spurious data are still present in the display. One of the key objectives of this present contract was to develop post-inspection-signal processing techniques which would be used to display umambiguous flaw data. As was discussed in Section VI, several techniques have been developed. When these techniques were applied to the data obtained from Component I as shown in Figure 49, all the ambiguities were removed and only the flaw data were displayed, as shown in Figure 50. The filtering techniques utilized are listed in the bottom portion of Figure 50.

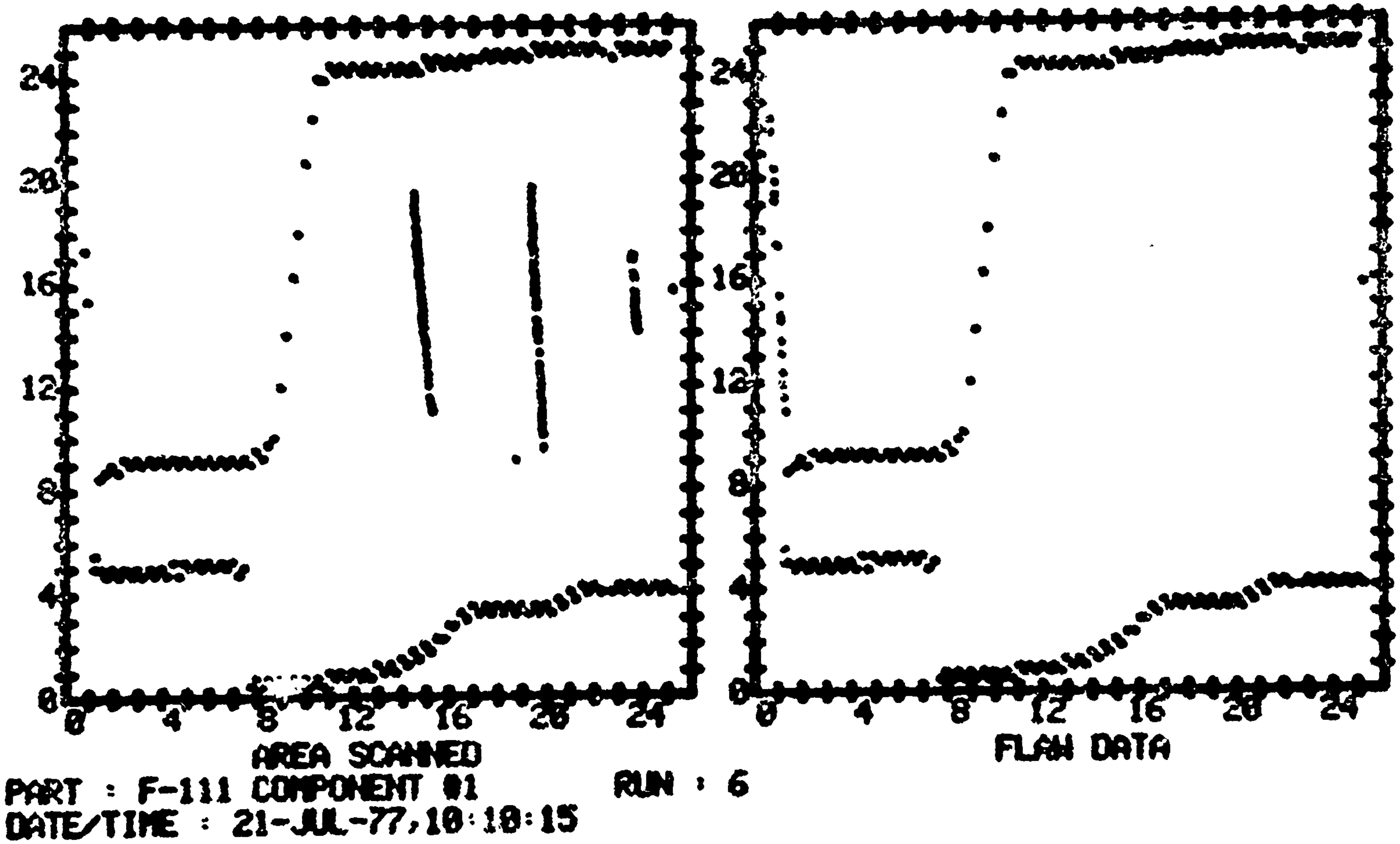


FIGURE 48. Plot of Radix Scan of Fillet Radii

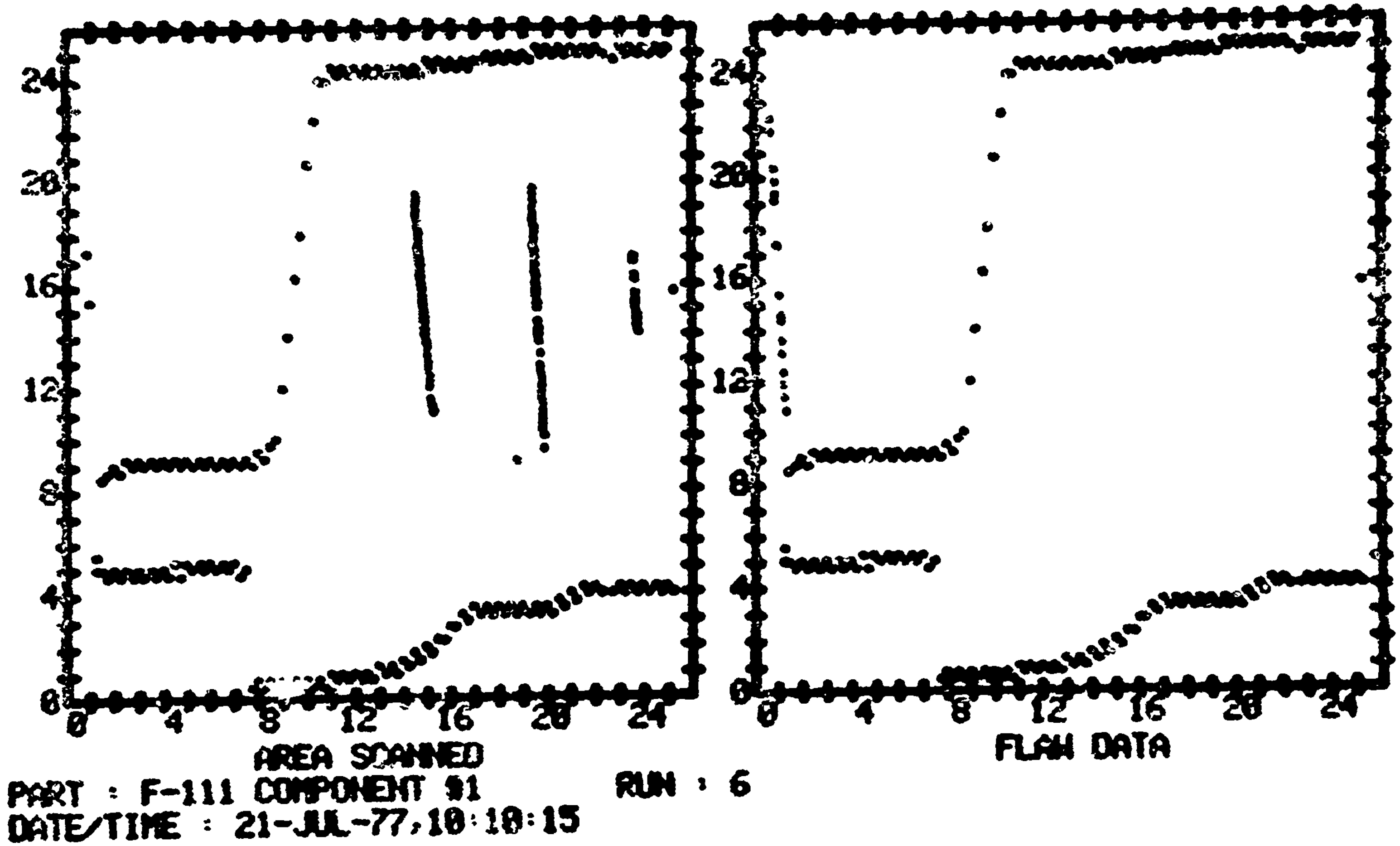
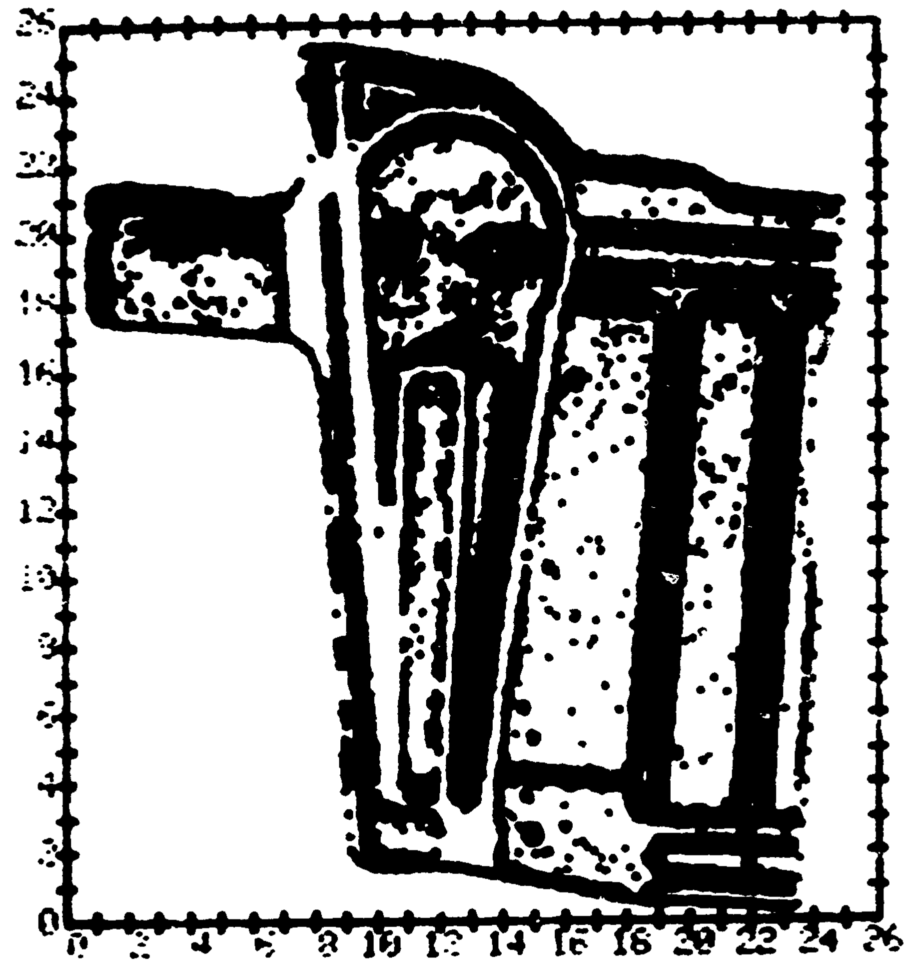
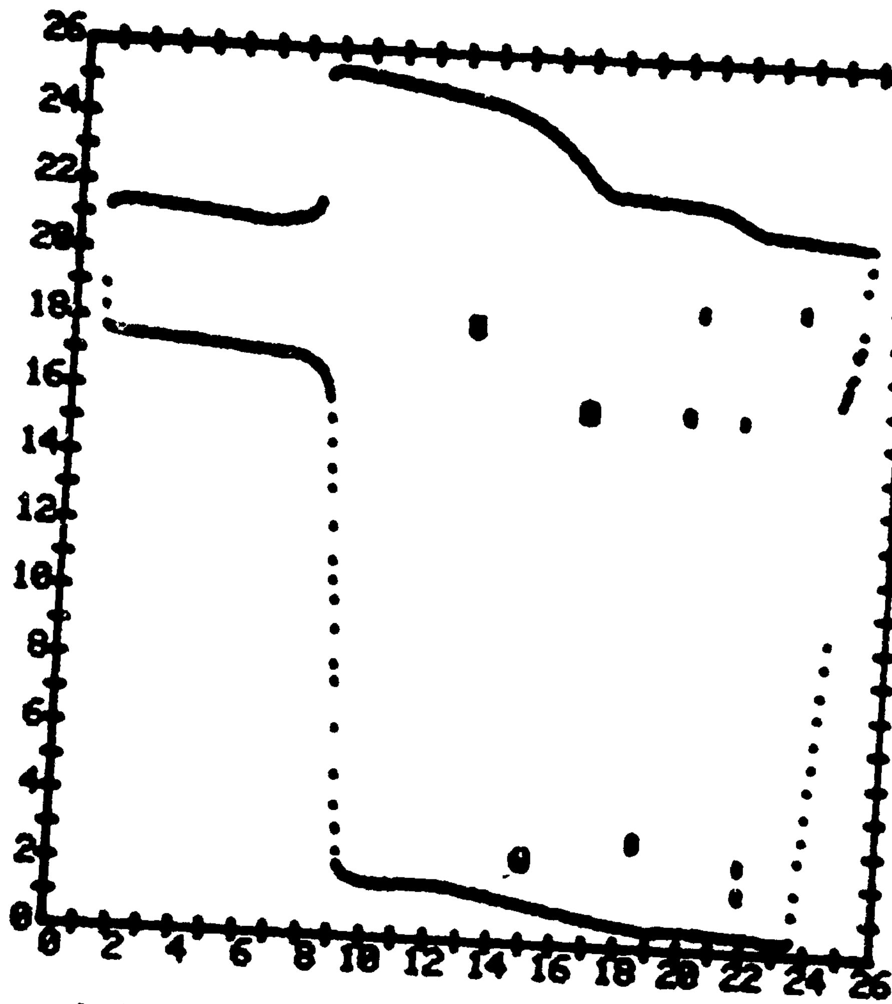


FIGURE 48. Plot of Radix Scan of Fillet Radii



PART F-111 COMPONENT #1 RUN 6
DATE/TIME 23-JAN-78, 06:21:21
AMPLITUDE RANGE FROM 1 TO 15

Figure 49. F-111 A1 Landing Gear Forging
All Possible Data.



PART: F-111 COMPONENT #1 RUN: 6
DATE/TIME: 01-FEB-78,13:27:55
CONSECUTIVE PULSES INCLUDED FROM 4 TO 14
AMPLITUDE PROFILE
DEPTH FILTER 0.45 TO 2.40
ADJACENT SCAN LINE FILTER

FIGURE 50. Total View of Component I Using Post-Processing

A comparison of the FBH's present in the component and the FBH's detected after the application of these filtering techniques can be seen from Figure 51. As can be seen, two 2/64-inch-diameter FBH's located in a rib were not detected. One of these contained a broken drill bit, and both of them are located about 2 1/2 inches from the top surface of the component. Actually signals from these two FBH's were present before the application of the filtering techniques, but they were weak signals and were removed by the filtering techniques. However, the 2/64-inch-diameter FBH located in the flange area (about 1 inch from the top surface) was easily detected. A 3/64-inch-diameter FBH containing a broken drill and located in a radius was also not detected. However, no signals from this FBH/broken drill area were above the noise level before the application of the filtering techniques. Thus, signal filtering did not affect the detectability of this FBH/broken drill.

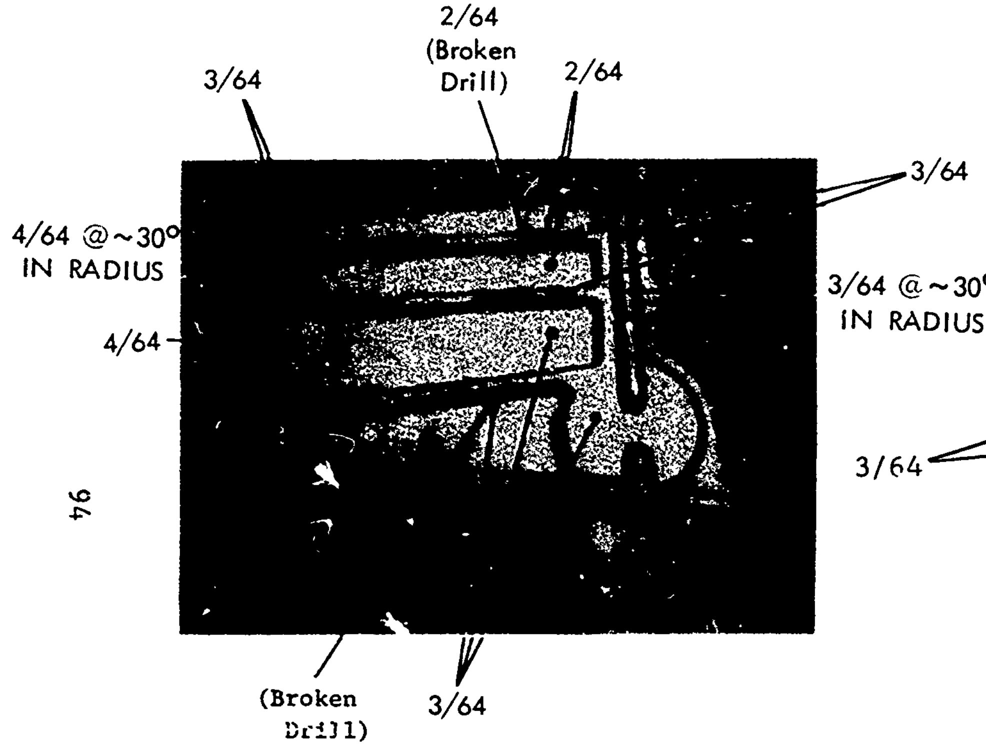
A 3/64-and 4/64-inch diameter FBH located in a radius and about 30 degrees off normal to the top surface of the component were detected both before and after signal filtering. A 3/64-inch-diameter FBH located in a rib and about 4 inches from the top surface of the component was also easily detected.

7.2 Ultrasonic Zone Scanning of Component III

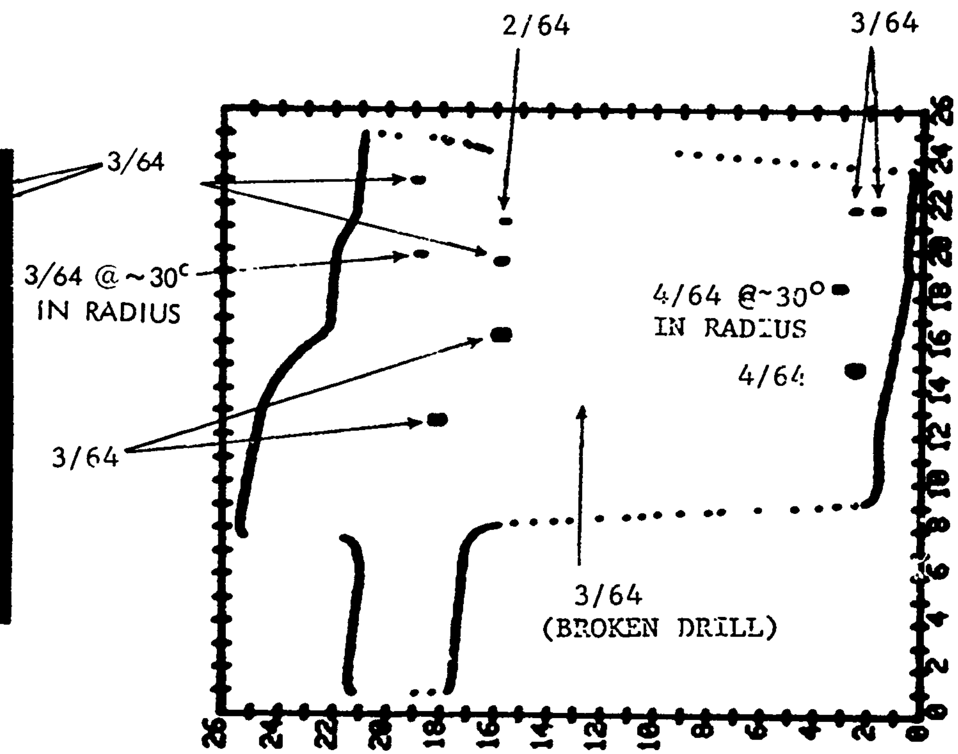
Component III was a F-16 bulkhead forging machined to final shape. A picture of the component selected for demonstration is shown in Figure 52. Also shown in Figure 52 are the 0.125-inch fillet radius and a 1 1/4-inch deep pocket area inspected as part of the demonstration. To demonstrate the detection capability of the optimized CAUIS, three 3/64-inch-diameter FBH's were drilled as shown in Figure 52. One of them was drilled with its axis parallel to the top surface and between the intersection of two webs to demonstrate that the system can detect flaws during inspection of pocket areas.

7.2.1 Zone Scan Results

Ultrasonic zone scanning of Component III was accomplished by placing the component on a specially built holder to raise it relatively evenly off the back-up plate. The holder consisted of three 3-inch long spikes of 1/2 inch in diameter which were placed at three extreme corners of the component. The component



F-111 LANDING GEAR FITTING (ALUMINUM FORGING)



C-SCAN RECORDING OF F-111 FORGING WITH POST INSPECTION SIGNAL FILTERING

FIGURE 51. Comparison of FBH's In Component I and Those Detected After the Application of Filtering Techniques

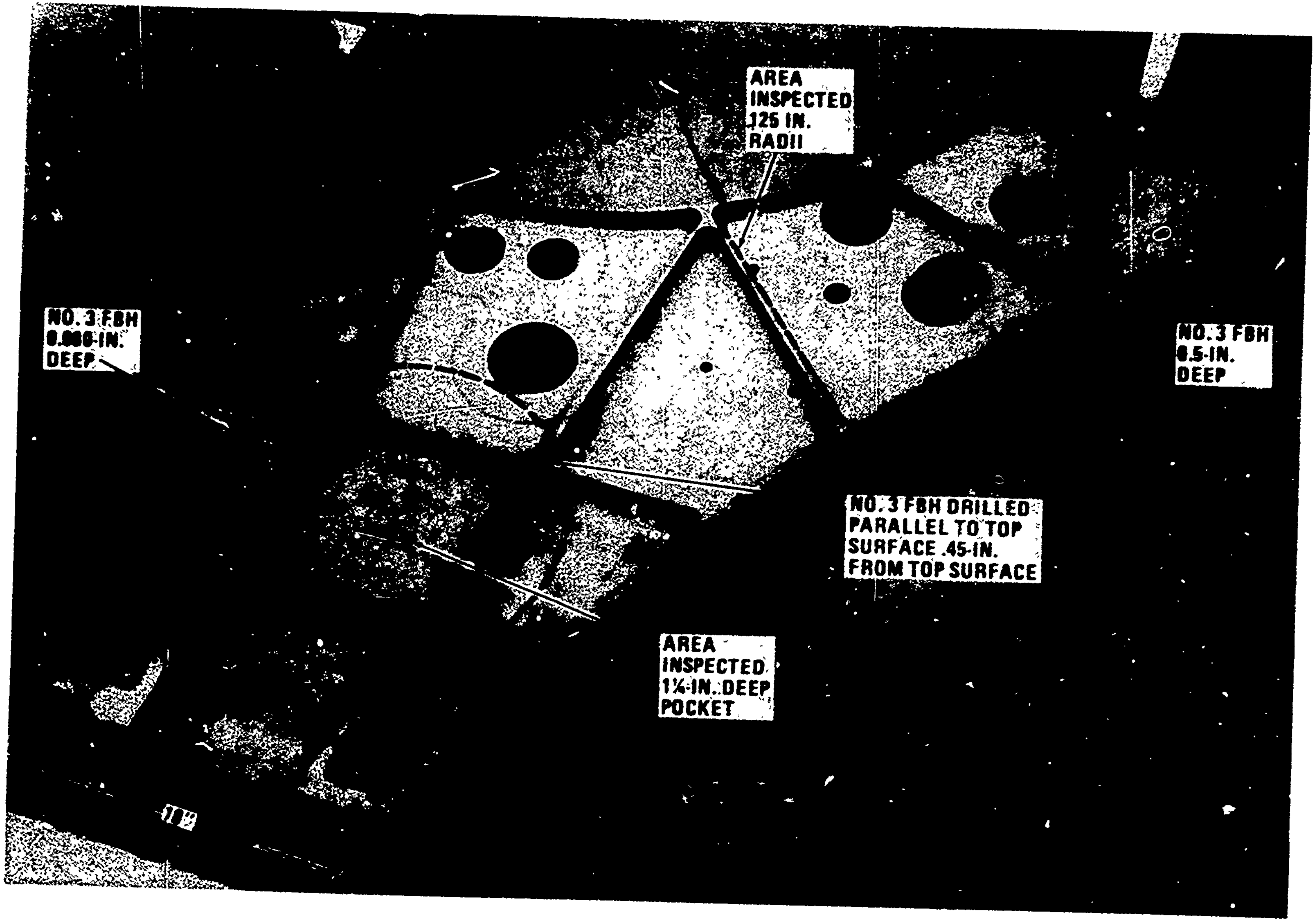


Figure 52. F-16 Bulkhead Forging With FBH and Areas Inspected

must be raised off the back-up plate to ensure separation of ultrasonic signals from the back surface of the component from those of the back-up plate for the Zone Scan method to work properly.

The zone scans performed on Component III included a Zone Ø scan, a Zone N scan, one vector scan of a 0.125-inch fillet radius, and a pocket scan. The .125-inch radius and pocket are indicated in Figure 52. Figure 53 is the result of the zone scans which showed the presence of two FBH's and a horizontal cylinder. This C-scan presentation was obtained after the application of the four filtering techniques, as indicated in the bottom portion of the figure. An approximate 16-fold enlargement of one FBH and the horizontal cylinder and a 32-fold enlargement of the second FBH along with their appropriate coordinates are shown in Figures 54 and 55 respectively. The resemblance of a cross section of a cylinder in Figure 55 is rather remarkable.

The FBH data shown in Figure 56 was obtained with the FBH located 0.08 inch from the top surface. One of the objectives of this program was the detection of a 3/64-inch-diameter FBH located 0.05 inch from the top surface. While the ultrasonic unit developed in this program operated in conjunction with a 10-MHz, focused, highly damped transducer can separate the signal of a FBH located 0.06 to 0.065-inch from the top-surface signal, the electronic gate in a computer-automated system cannot reliably separate or gate the signal unless the FBH is located 0.075 to 0.08-inch from the top surface of the component. Operating at a frequency greater than 10 MHz, careful selection of transducers, impedance matching, etc., can improve the resolution. But a 3/64-inch-diameter FBH located 0.05 inch from the top surface of the component cannot be reliably gated with a computer-automated system operating at 10 MHz or some lower frequency.

7.2.2 Pocket-Scan Results

The pocket within the circled area of Figure 52 was scanned using a mirror attachment to redirect the sound beam 90 degrees from its direction of propagation and normal to the ribs of the pocket. The scans were in some X-Y vector direction and indexed in the Z direction. Figure 57 is the display of the pocket scan in the X-Y coordinate for all Z values. The display shows the rib thickness (1/8 inch for the thin ones and 5/16 inch for the thick ones) and the FBH indications located at the upper left-hand corner of the pocket. The other black dots around the flaw

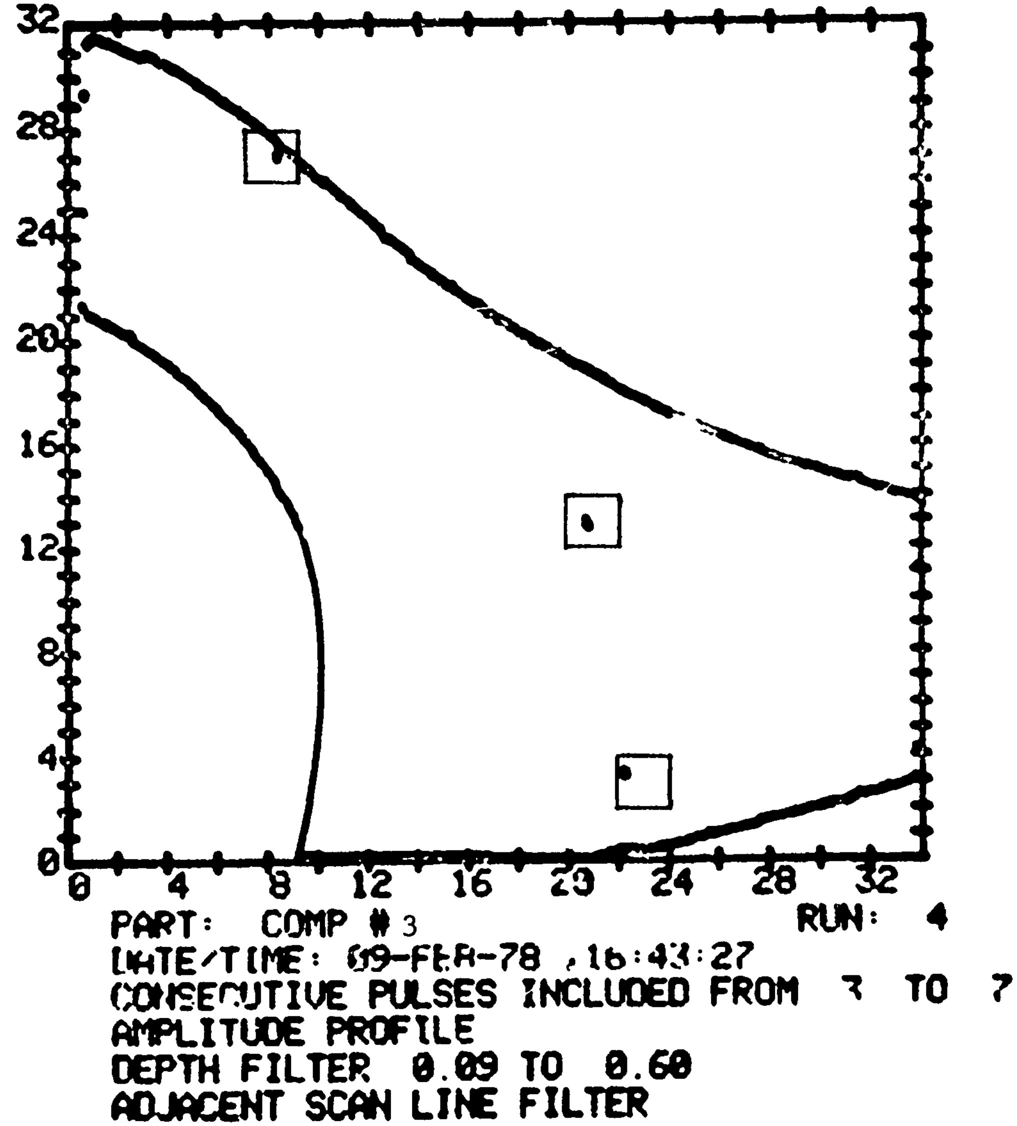


FIGURE 53. View of Component III Using the Four Indicated Fillers

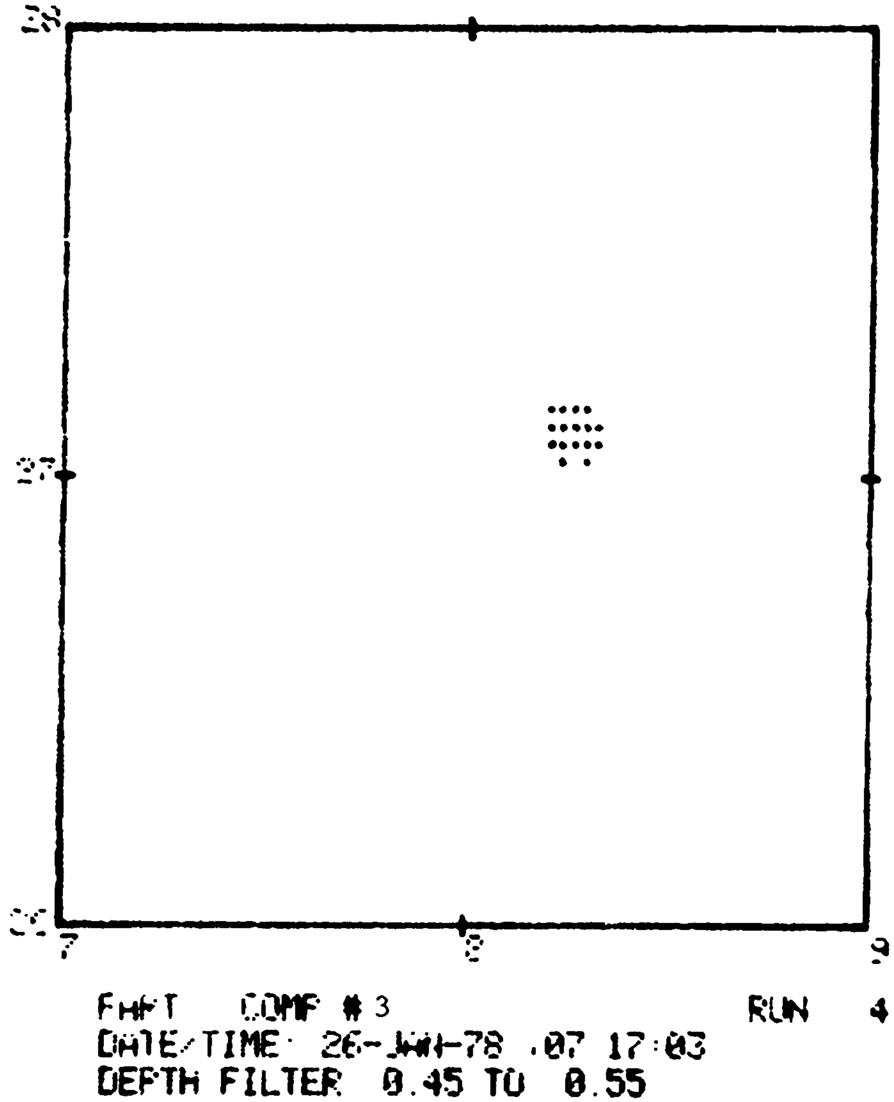


Figure 54. C-Scan Recording of One FBH in Component III - Magnification 16

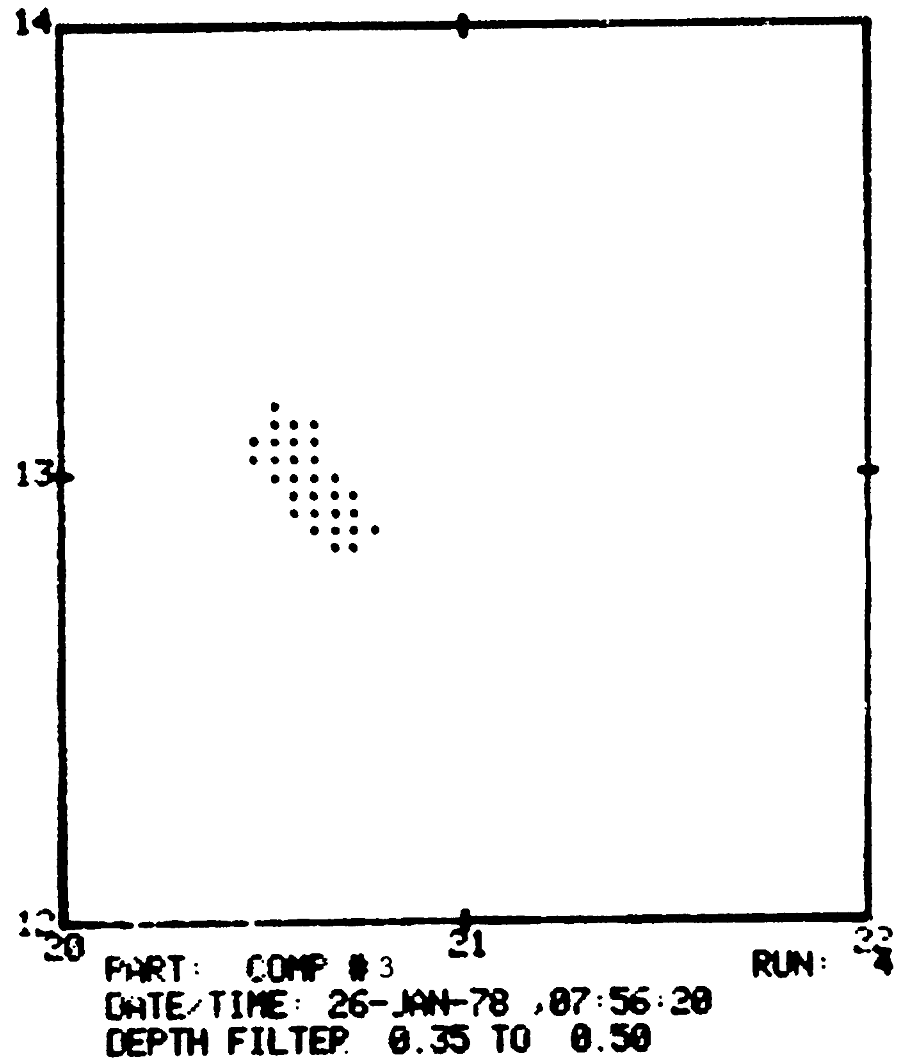


Figure 55. C-Scan Recording of Horizontal Cylinder-Magnification 16

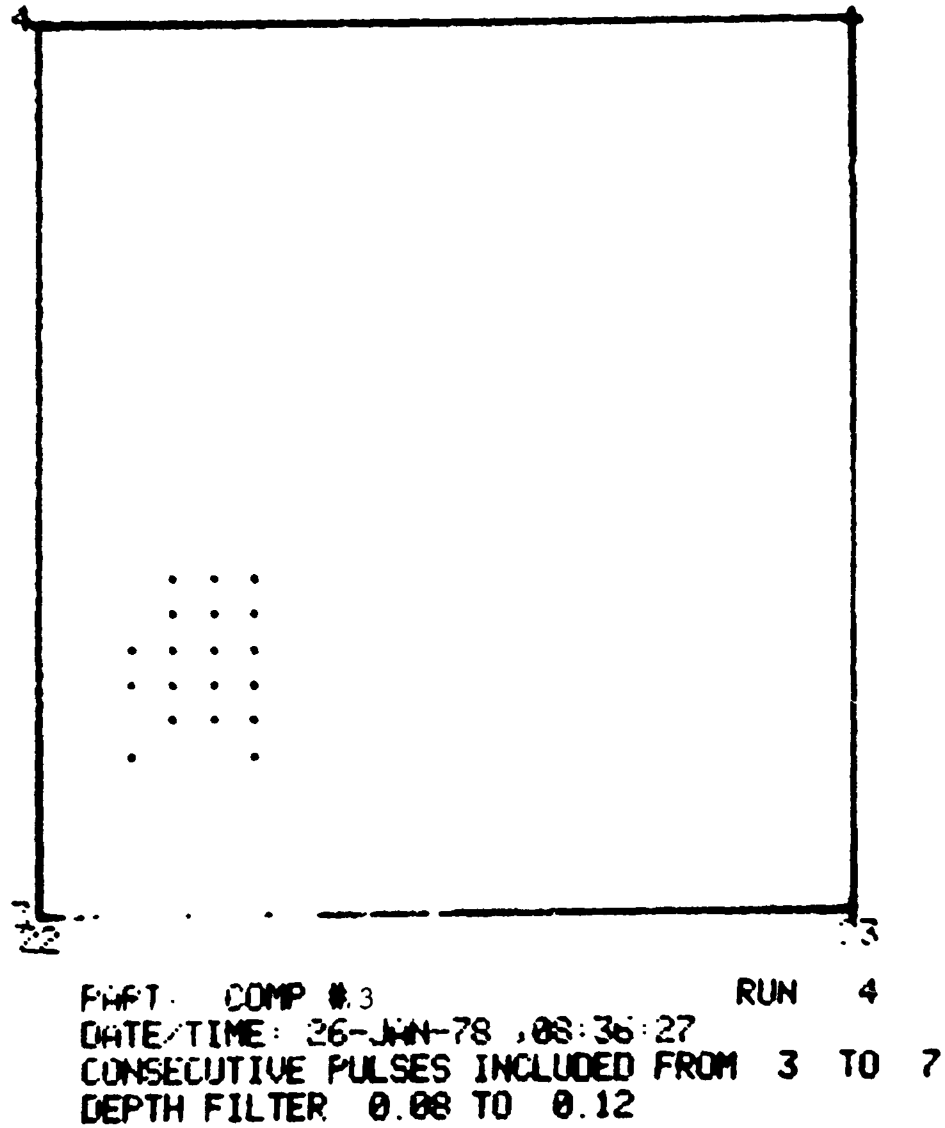


Figure 56. C-Scan Recording of Another FBH in Component III- Magnification 32

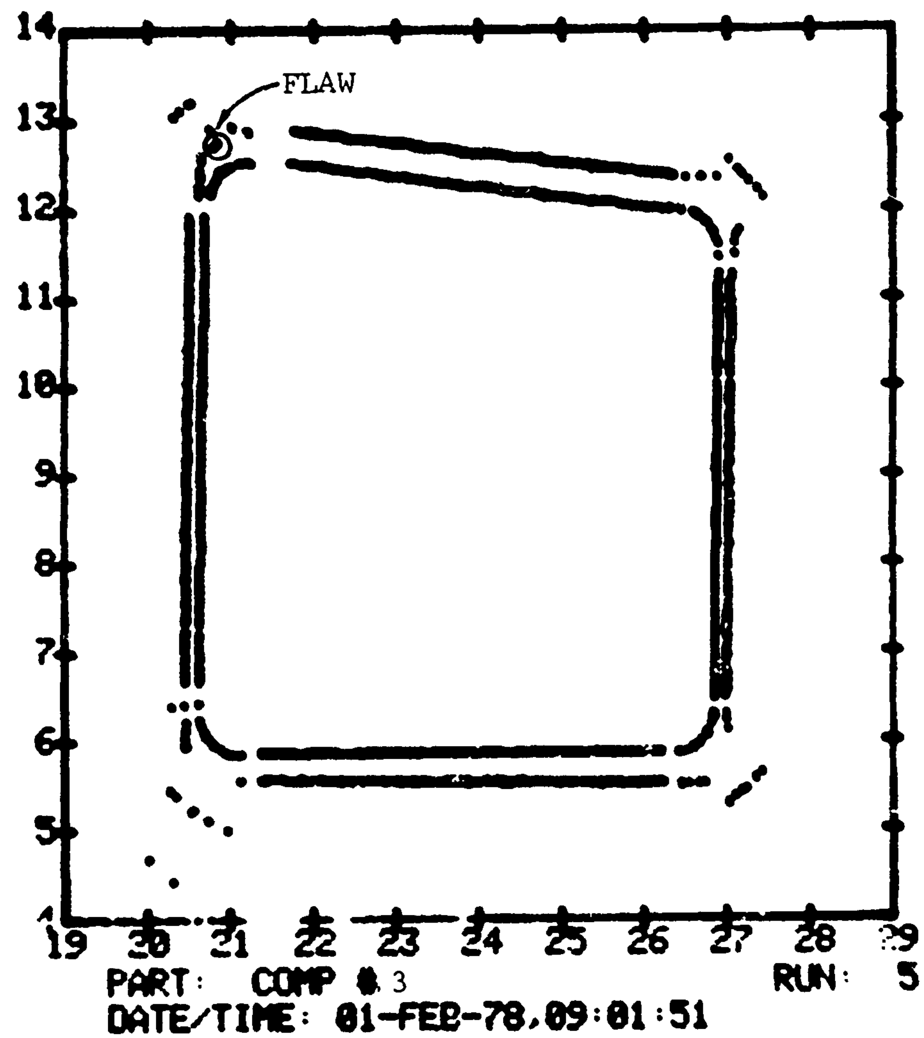


FIGURE 57. Top View of Pocket Scan on the F-16 Isothermal Bulkhead

indication are signals from the adjacent vertical radius. A more unambiguous display of the FBH signals is shown in Figure 58, where the signals are displayed in the Z-coordinate versus the arc length of the vertical radius. The vertical radius of approximately 1/2 inch was divided into 11 equal intervals. Signals were received from two Z positions and two arc length positions. The display of the horizontal FBH as shown in Figure 55 and the one in Figure 58 can be combined to produce a three-dimensional display of the FBH.

The total-inspection and post-inspection data processing time of Component III was slightly more than four hours, which included the zone scans, one radius vector scan, and one pocket scan. The inspection time included calibration, set-ups, and mirror attachment time. The zone scans took approximately 2 1/2 hours with an average scan speed in excess of 6 inches per second. The radius vector and the pocket scan took approximately 1 1/2 hours. The pocket scan was particularly slow because of the manner in which the four vertical radii were scanned. The scan time of the pocket could have been improved considerably if the scans were made in the Z direction and indexed to one of the 11 arc-length positions. The straight portion of the webs were inspected at speeds of over six inches per second; however, when the scan speeds of the vertical radii were combined with the straight portion, the average inspection speed was equal to only approximately 1 1/2 inches per second. It could be improved to 3 to 4 inches per second.

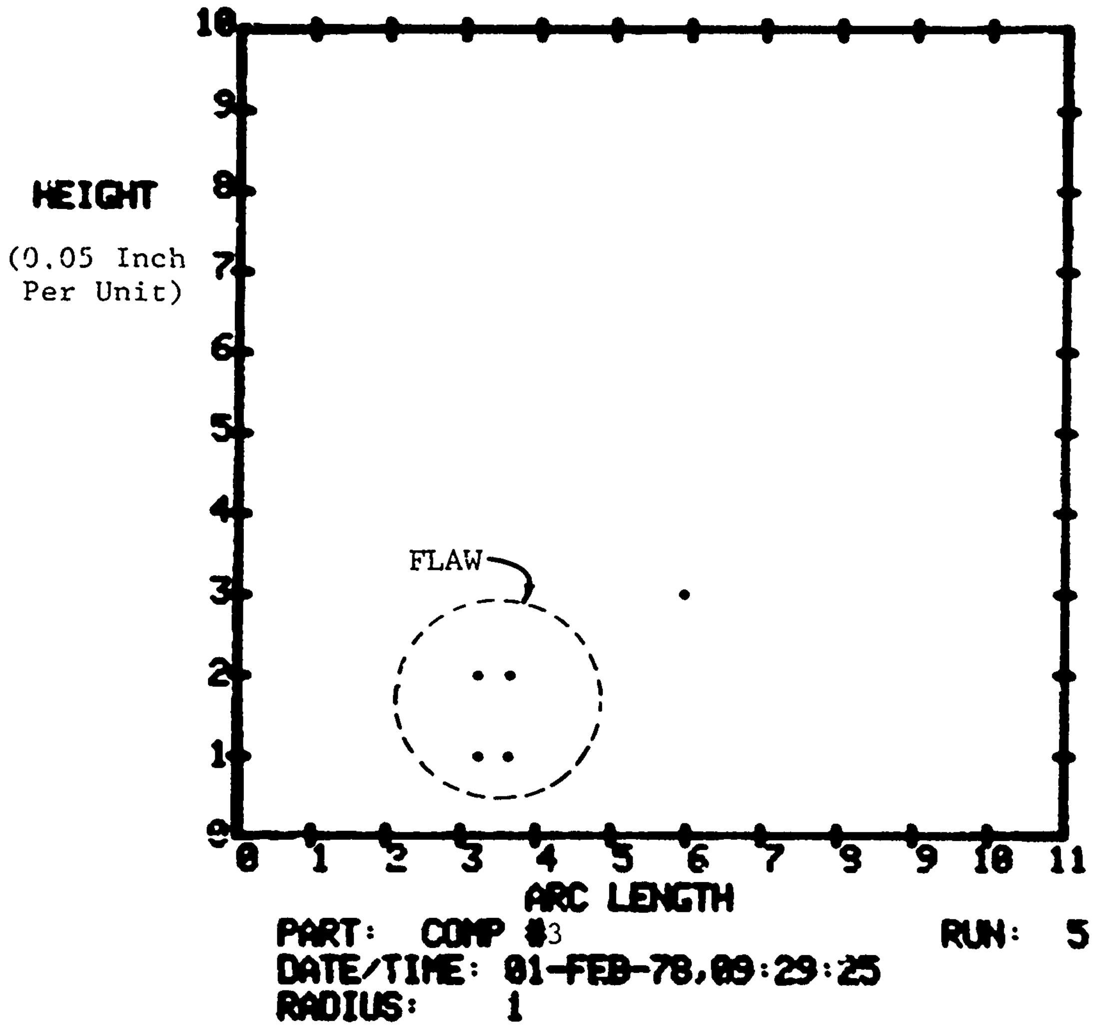


Figure 58. C-Scan Recording of Horizontal Cylinder in Z-Arc Length Plane of Component III.

SECTION VIII

CONCLUSIONS AND RECOMMENDATIONS

The objective of this program was to optimize the CAUIS, which was developed in a previous AFML contract (F33615-72-C-1828). The capabilities and limitations of the CAUIS were documented in Final Report AFML TR-75-82. The conclusions and recommendations are repeated in Appendix A of this present report.

The conclusions of the optimized CAUIS program are as follows:

1) Complex airframe components, both in the rough forging shapes and in near-net shapes, can be inspected for defects by the optimized CAUIS with an average scan speed of more than six inches per second.

2) A picture of a rough-forging and a near-net-shape component inspected in this program is shown in Figures 1 and 3 respectively. These components have radii from 1/8 inch on up, pockets on both sides, cut-outs, and other complex geometries that are of common occurrence in typical airframe components.

3) While 1/8-inch fillet radii can be scanned, detection of flaws beneath the 1/8-inch radii is made difficult by the focusing action of the sound beam by the radii.

4) Detection of FBH-like flaws that are 0.05 inch beneath the surface by the optimized CAUIS is not feasible. The practical state-of-the-art capability of the optimized CAUIS is around 0.075 to 0.08 inch for most airframe aluminum alloys. However, the equipment operating in conjunction with the human eye can distinguish flaw signals that are about 0.055 to 0.06 inch beneath the surface.

5) The concept of ultrasonic zone scanning (UZS) with the associated hardware and software was developed by this program, and it has been proved successful for inspection of the two airframe demonstration components of this program.

6) The UZS method is particularly adaptable to the inspection of near-net or net-shape airframe components.

7) Several contour-following or scanning methods for the inspection of complex airframe components were evaluated as part of this and the previous program. They are:

   a. Mechanical probes with microswitch stops
   b. Capacitance probes with non-contact stops
   c. Ultrasonic transducer arrays
   d. Eddy-current proximity sensors
   e. Use of numerical control tape
   f. Use of computer aided design data control
   g. Vector-drive scanning
   h. Vector-drive scanning with self-organizing control
   i. Ultrasonic zone scanning

8) The ultrasonic zone scanning was the most adaptable and practical method for the inspection of near-net or net-shape complex airframe components.

9) The adaptability and flexibility of the optimized CAUIS was reaffirmed with its application to the successful inspection of a near-net-shape, Ti-powder, hot, isostatically pressed F-16 horizontal pivot fitting which was fabricated and inspected as part of AFML Contract F33615-77-C-5005.

Despite the success of the optimized CAUIS to inspect the demonstrated rough and near-net shape forging components, there remains much work to be done before the optimized CAUIS can become a routine production inspection tool. Some of the recommended future developmental efforts are:

1) Conduct an engineered producibility determination in a production environment to establish the reliability of flaw detection and the feasibility of production inspectors to operate the CAUIS. Probability of flaw detection in advanced composite and Al-and Ti-powdered aircraft structures is of particular interest.

2) Develop software and hardware capabilities within the optimized CAUIS to simultaneously determine dimensions and tolerance of the component while inspecting for defects.

3) Incorporate image reconstruction schemes that have been developed by the program of the NDE Center to provide quantitative display of flaw dimensions and types. The scanning capabilities of the CAUIS is particularly suitable for image reconstruction work.

4) Develop phased multiple transducer arrays to introduce compressional waves at different angles of incidence for rapid inspection of randomly oriented flaws such as might be occurring in Ti-and Al-powdered components and for image reconstruction.

APPENDIX A

CONCLUSIONS AND RECOMMENDATIONS

OF AFML CONTRACT F33615-72-C-1828

At the completion of this 33 month contract, the following conclusions are made:

1) A computer-automated ultrasonic inspection system using off-the-shelf ultrasonic, electronics, and computer components has been designed, built, and made operable.

2) The system operates primarily in the reflected compressional and shear mode, but it is capable of operating in the delta scan mode.

3) The system can be operated manually, by console control, or by total closed-loop computer control of the five axes: X, Y, Z, θ, and ϕ. It can scan at speeds up to 10 inches per second on flat parts. The system also controls the speed of the scan.

4) The system has successfully inspected an aircraft-jet-engine disk (sonic shape) and achieved a greater than 50-percent savings in inspection and calibration time. It has inspected typical airframe forgings which cannot and are not being inspected by conventional ultrasonic inspection. It has successfully inspected a complex diffusion bonded aircraft structure.

5) The system has inspected structural components with curved near and far surfaces, radii from 0.75 inch and larger, holes in near and far surfaces, and through holes.

6) The system automatically adjusts the db setting during the calibration phase to compensate for transducer and equipment variation.

7) The system has digitized RF waveforms and performed Fourier transforms.

8) The system has and can remove flaw indications from outside of the final or net shaped structural component by performing a series of logic and spatial filtering routines. Blind zones caused by step discontinuities can be reduced by the multiple flaw gate.

9) Defect indications are presented in a conventional C-scan display on a storage scope (graphic terminal).

10) Post inspection analysis include bilities.

- Amplitude discrimination of defect data provides a very effective and expedient aid in the acceptance or rejection decision.
- Defect indications can be displayed as an isometric ploc of defect amplitude on the X and Y axes.
- Areas with defect indications are searched with the defect homing routine to obtain the coordinates (X, Y, Z, θ, and Ø) which yield the largest ultrasonic amplitude to determine defect orientation and detect randomly oriented defects.
- Areas with defect indications can be expanded to give a more detailed view of the defect cross section.

11) The system records inspection results permanently on magnetic disk. The results can be recalled in near real time.

12) The system reduces, but does not remove, operator interpretation on potentially rejectable flaws and operator involvement with the overall inspection requirements.

13) A computer automated ultrasonic inspection system is feasible and reliable. During the 19 months in which the computer was in operation, it failed to operate on six occasions. The computer required outside services on only two of these occasions. The other occasions, it was repaired by in-house electronic personnel.

The following areas of further improvements and developments are recommended.

1) A large amount of ultrasonic data are being collected and available. More and better software logic, signal processing schemes, and spatial filtering schemes need to be developed to produce a clear and ambiguous presentation of results.

2) A contour-following scheme which can rapidly and reliably follow and inspect radii between 1/8 to 3/4 inch must be developed.

3) Software and hardware schemes need to be developed and made operable with conventional off-the-shelf ultrasonic equipment to reduce the top surface envelope to approximately 0.05 inch.

4) A scheme to identify the radius of curvatures and correct for their effects on the focusing and defocusing of ultrasonic sound beams and energy density should be developed.

5) The ultrasonic transducer housing assembly must be miniaturized so that it can be inserted into small pockets (2-3 inches in diameter) and inspect for defects in these pockets.

6) Software schemes need to be developed to reconstruct the image of the defect when the defect can be illuminated from several directions, such as the flaw homing routine.

7) The capability of the system to inspect actual complex aircraft structures reliably and cost effectively needs to be evaluated.

8) Signal processing schemes for defect dimension determination need to be implemented as they become available.

9) The calibration and set up procedure and operator-system interface need to be streamlined and simplified for potential reduction to production practice.

10) For a given inspection, a great deal of data are recorded and stored. Software schemes need to be developed to compact or reduce the amount of data necessary to have complete inspection documentation.

11) Many of the capabilities described in the conclusion have been demonstrated on an individual basis. These capabilities need to be combined and integrated into a sing. master program that possesses as many of the individual capabilities as possible or necessary.

APPENDIX B

SYSTEM OPERATION

When the procedures given in this section are followed, ultrasonic inspection can be performed in near real time. Only care in choosing the proper settings on ultrasonic equipment and careful calibration adjustments are required to operate the system. A complete description of the software is presented in Appendix E.

B.1 System Start-Up

A typical start-up procedure is as follows:

<u>Computer</u>

1) Turn main power circuit breaker to ON.
2) Press processor switch to HALT.
3) Turn key to POWER.
4) Put in disk packs if load light is on.

NOTE: System device DK0 must contain the operating system pack. The bottom line unit is designated DK1 and is used for DATA storage.

5) Position disk drives to RUN.
6) Place 173110 - in switch register.
7) Depress LOAD ADDRESS.
8) Set processor switch to HALT TO ENABLE.
9) Depress START switch.

Computer teletype response unit:*

---

*The communication with the computer is presented in standard format used by Digital Equipment Corporation (DEC). All computer output is underlined, while the operator-typed input is not underlined. The carriage return terminator at the end of each typed line is represented by the symbol ↲ .

DOSØØ1
DOSVØ8-Ø2
DA 01-FEB-78
TI 07:30:00

LOG 2ØØ,2ØØ

DATE: 01-FEB-78
TIME: 07:30:05

Graphic Display

1) Graphic Terminal

   a) Turn power switch to ON.
   b) After 10 seconds, push PAGE button (erases the screen).

2) Hardcopy Unit

   a) Turn power swith to ON.

Ultrasonics

1) Depress power switch (switch should light up).

Scanner System

1) Turn power switch to ON for the control and display units for all five axes.

2) Lower transducer 5 inches into water and release air bubbles from face of transducer.

B.1.1. Run Mode: Initial

After the typical start up sequence has been performed as described in System Start Up, the computer corresponds with a $, as shown in paragraph E.1, showing that the DOS monitor is ready to perform the RUN commands. The initiation of the test starts with the operator's typing of RUN AUISCM and follows with one of the following responses:

The INITIAL run mode prepares the system to start a new file for test data and, consequently, it clears files of all old test data* stored in DK1. Therefore, hard copies of the desired records should be made of any scans before going into the INITIAL input string.

Since the DK1 disk is cleared by the INITIAL program, either a zeroed disk or a disk that has been used previously with the RUN AUISCM program has to be used. The program allocates 4700 contiguous blocks out of a total of 4800 blocks on the disk. If the disk has been used previously, the format is set so that it can be cleaned or zeroed and made ready to start over with the new data files.

An example of the Initial Communication is shown in Figure B1.

B.1.2 Run Mode: List

The LIST routine prepares a list on the Tektronix CRT of all the test runs that have been made and stored on DK1. It shows the run number, the part name, side name, part serial number, and percent of disk memory used for each of the runs.

The listing is used to aid the operator in identifying the runs for data retrieval and presentation. Example of the LIST procedure and the output information is shown in Figure B2.

---

* The operator should be aware of the computer action taken after receipt of a run mode command in order to prevent a loss of old data.

```
SEU AUISCN

RUN MODE = INITIAL

RUN NUMBER : 1

* 1

PART NAME : F-111 COMPONENT #1

* 2

SIDE NAME: ALPHA

* 3

PART SERIAL NUMBER : CAUIS #1

* 4

OPERATOR : ARNETT G R

* 5

TEST FREQUENCY : 5.

* 6

TRANSDUCER S/N : A0563

* 7

TEST SITE : GD/FW/MRL

* 8

TEST MATERIAL TYPE : ALUMINUM

* 9

SCAN DIRECTION : Y

* 10

SCAN SPEED : 10.0

* 11

INDEX SPEED : 4.0

* 12

X/Y INCREMENT : 50

* 13

Y MATRIX SIZE : 27

* 14

X MATRIX SIZE : 25

* 15

SPACE ALLOWABLE : 0.5

* 16

PULSE RATE(MILS/PULSE) : 40

* 0

CHANGE ANYTHING ? NO
```

FIGURE B1. Initial Mode Communications

SFU AVISCM

RUN MODE = LIST

RUN	PART NAME	SIDE NAME	PART SERIAL NO	% USED
1	TAPERED BLK	RECTANGU	1	0.14
2	COMP 02	ALPHA	CAUIS 01	0.33
3	COMP 02	ALPHA	CAUIS 01	3.01
4	COMP 02	ALPHA	CAUIS 01	78.56
5	COMP 02	ALPHA	CAUIS 01	2.78

TOTAL USED : 84.82 %

FIGURE B2. List Procedure and Output Information

B.1.3 Run Mode: DATA

At the completion of the typical start-up procedure, the system is ready for operation. Either of two modes of operation are available. One is the initial procedure for cleaning the disk; the other is the routine method of data taking. The former is used only in re-zeroing a used disk pack. The DATA mode adds the new information to the existing data records on the disk.

Typing DATA in response to the computer question of run mode starts the data acquisition sequence. The input values from the last data cycle will be used for identifying the current data run when the operator elects to skip further inputs. An example of the communication for DATA mode is shown in Figure B3 . The input values are displayed on the Tektronix scope for review in Figure B4.

The input values are displayed again after a change has been made as shown in Figure B5 . If the operator does not elect to skip the input information, he can selectively edit the information by typing YES in response to CHANGE ANYTHING. The system responds with an *. The number of the line to be changed is input and the information can be changed. In Figure B5 the operator's name has been changed. This sequence is repeated for each line to be edited.

If the test run is not terminated properly, the data will not be stored on DK1. Furthermore, the input information taken during start up will not be kept. When the program is restarted, the input files that were used for that run will be those from the last properly terminated run.

The operator can properly terminate a data run by allowing the scanner to complete its required scan or manually actuating Switch 15 of the computer switch register. Any other method will result in the loss of data.

```
$RU AUISCN

RUN MODE = DATA

RUN NUMBER : 6

CHANGE ANYTHING ? YES

* 4

OPERATOR : BELL J R

* 0

CHANGE ANYTHING ? NO
```

FIGURE B3. Data Mode Communication

```
 1) PART NAME : COMP #2
 2) SIDE NAME : ALPHA
 3) PART SERIAL NUMBER : CAUIS #1
 4) OPERATOR : ARNETT G R
 5) TEST FREQUENCY :    5.0
 6) TRANSDUCER SERIAL NUMBER : 0.5" TRANS
 7) TEST SITE : GD/FW/MAL
 8) TEST MATERIAL TYPE : ALUMINUM
 9) SCAN DIRECTION : Y
10) SCAN SPEED :  10.00
11) INDEX SPEED :    4.00
12) X/Y INCREMENT :      50
13) Y MATRIX SIZE :      32
14) X MATRIX SIZE :      34
15) SPACE ALLOWABLE :   0.30
16) PULSE RATE(MILS/PULSE) :    50
```

FIGURE B4. Input Values Displayed on Tektronix Scope

```
 1) PART NAME : COMP #2
 2) SIDE NAME : ALPHA
 3) PART SERIAL NUMBER : CAUIS #1
 4) OPERATOR : BELL J R
 5) TEST FREQUENCY :    5.0
 6) TRANSDUCER SERIAL NUMBER : 0.5" TRANS
 7) TEST SITE : GD/FW/MAL
 8) TEST MATERIAL TYPE : ALUMINUM
 9) SCAN DIRECTION : Y
10) SCAN SPEED :  10.00
11) INDEX SPEED :    4.00
12) X/Y INCREMENT :      50
13) Y MATRIX SIZE :      32
14) X MATRIX SIZE :      34
15) SPACE ALLOWABLE :   0.30
16) PULSE RATE(MILS/PULSE) :    50
```

FIGURE B5. Changed Input Values Displayed on Tektronix Scope

B.1.4 Run Mode: DELETE

The DELETE routine is used to remove the data from the last run from DK1. It will remove only the data from the last run on the disk. The DELETE routine can be used repeatedly to remove the test data and input information from the disk.

B.1.5 General Information on Input Commands

The part serial number and run number are used to catalog the test data. These values must be unique (distinctive and separate), for each scan. These values are used for filing the data on DK1 for retrieval later. The run numbers start at 1 and continue numerically up to a 6-digit number. However, 6 letters or any combination of unique alphanumeric characters can be used. The part serial number can be any designation up to 14 alphanumeric characters.

B.1.6 Post-Processing Execution

After the typical start-up sequence has been performed as described in System Start-Up, the computer corresponds with a $, as shown in paragraph E.1, showing the DOS monitor to be ready to perform the RUN commands. The initiation of the test starts with the operator typing RUN POSTPR. The operator is then asked to identify the run number desired and is then paged for information regarding the options, listed in the 4010 scope, he desires. Figure B6 shows a listing of the available options. Figure B7 shows a typical command sequence for a post-processing run.

```
*** OPTIONS AVAILABLE IN POST PROCESSING ***

 1) PLOT BACK SURFACES ONLY
 2) AMPLITUDE FILTER
 3) DEPTH FILTER
 4) CONSECUTIVE POINTS FILTER
 5) OPTIONS 2 AND 3
 6) OPTIONS 2 AND 4
 7) OPTIONS 3 AND 4
 8) OPTIONS 2, 3, AND 4
 9) ADJACENT LINE FILTER
10) OPTIONS 3 AND 9
11) TOP SURFACES ONLY
12) EXIT
```

FIGURE B6. Options Available in Post-Processing

```
RUN POSTPR
ENTER RUN NUMBER: 6
REPORT? NO
AREA FILTER? NO
CHOOSE RUN OPTION FROM 4010 SCOPE: 7
ENTER DEPTH FILTER NUMBER: 500
ENTER MINIMUM DEPTH: .4
ENTER MAXIMUM DEPTH: 2.5
EXCLUDE DEPTHS? NO
ENTER CONSECUTIVE PULSE LOWER LIMIT: 4
ENTER CONSECUTIVE PULSE UPPER LIMIT: 15
AMPLITUDE PROFILE? NO
ENTER RUN NUMBER: 6
REPORT? NO
AREA FILTER? YES
CHANGE LIMITS? YES
X START: 14
X STOP: 20
Y START: 15
Y STOP: 20
CHOOSE RUN OPTION FROM 4010 SCOPE: 10
ENTER DEPTH FILTER NUMBER: 500
ENTER MINIMUM DEPTH: .45
ENTER MAXIMUM DEPTH: 2.45
EXCLUDE DEPTHS? NO
ENTER CONSECUTIVE PULSE LOWER LIMIT: 3
ENTER CONSECUTIVE PULSE UPPER LIMIT: 14
AMPLITUDE PROFILE? YES
DISPLAY AMPLITUDES = 1 ? NO
START-STOP MINIMUM AMPLITUDE: 7
MAXIMUM AMPLITUDE: 15
```

FIGURE B7. Command Sequence For Typical Post-Processing Run

APPENDIX C

SCANNING SYSTEM

A digitally controlled scanning system, using ultrasonic transducers as the sensors to detect flaws, has been designed, built, and placed in operation. The system is used to locate flaws in complex forgings. The ultrasonic head assembly can be moved in the X-and/or-Y axis at rates between 0.010 and 10 inches per second, depending on the complexity of the forging surface being scanned. This section will describe the mechanical scanner, test tank, rotate and tilt assembly, normalcy control system, and the standoff control circuit. The control console is shown in Figure 18.

C.1 X-Y Mechanical Scanning System

The test tank was purchased from Automation Industries, and the scanning system was designed and built at Convair. The electronics to control the 5-digital stepping motors were purchased from Summit Engineering Corporation. The interfacing between the scanning system and the computer was done at Convair.

C.1.1 Test Tank

The test tank has inside dimensions that are 4 ft wide, 6 ft long, and 3 ft deep. It has 1 x 1-ft window installed in the side so the operator can easily see the transducer as it scans the forging. The tank is sturdily built so it can hold heavy forgings without damage. A leveling plate is mounted on 4 hydraulic cylinders inside the tank. This plate can be leveled with these jacks by manual manipulation of hydraulic pumps located on the front of the tank. This leveling device is used to level the forgings before the scanning begins.

A water filter has been installed on the tank, and the tank has been plumbed for inlet water and drainage. The water filter can be cleaned by reversing the water flow through the filter.

C.1.2 X-Y Scanner

The configuration of the scanner is shown in Figure 19. It will scan in either the X-or-Y axis and index in the other axis. The unit was assembled primarily from purchased parts,

but some parts were machined and assembled by the Machine Tooling Group at GDFW.

The scanner frame was constructed from an aluminum U channel bolted to the top of the tank. Support blocks made by Berg, Inc. support the complete structure located on top of the immersion tank. On both sides of the tank steel shafts, one inch in diameter are supported by the Berg support blocks and are mounted to run parallel to the X-axis. Four ball-bearing support brackets carry the bridge. These are fastened to two aluminum blocks that carry two 1.0-in. ground rods that act as supports for the Y-axis (platform) movement.

Two drive motors and gear boxes are positioned on the support frame and drive the bridge and platform through three sets of POW-R-TOW cable chains. Two sets of chains, one on each side of the bridge, are driven from a common shaft to reduce the bending movement on the bridge. One long chain is wound around in the pattern shown in Figure 19 to drive the platform. As the bridge moves, the platform will stay in the same relative position with respect to Y movement.

The cable chains are constructed from steel cables with polyurethane rollers to form a strong, flexible, quiet, lube-free drive. The cable chain is corrosion-proof and gives minimum backlash. The cable chains have guides installed to prevent vibrations.

C.1.2.1 X- and Y-Axes Drive Motors

Separate stepping motors with 500-in. oz of torque drive the transducer carriage in the X- and Y-axes. These motors, Model 6061B with dual shafts, were manufactured by Sigma Instruments, Inc. These motors step from 10 to 10000 steps per second and each step moves the transducer carriage 0.001 in. in the half-step mode and 0.002 in. in the full-step mode. The primary mode of motor operation is the half-step mode. An internal jumper must be moved to switch to the full-step mode. The half-step mode is used to reduce motor oscillations at less than a 1-KHz stepping rate. These oscillations are standard with all stepping motors operating in the full-step mode.

Each motor drives through a 15:1 gear reducer, which gives an available output torque from the reducer of 7500-in. oz (15 x 500-in. oz) at the lower stepping rates. The available torque decreases at the higher stepping rates.

C.1.2.2 X-and-Y Axes Motor Controls

Each motor has a separate controller, which was purchased from Summit Engineering Corp. Each controller, which is called a preset control unit Model 8151C, is designed to fill the need for an electronic control which (from a thumbwheel or computer input command) will output the programmed number of pulses and direction command to the stepping motor driver. These output pulses are automatically accelerated and decelerated by the setting of internal potentiometers. The maximum output pulse rate (speed) is adjustable up to 10,000 steps per second by an internal adjustment. Once the maximum output pulse rate is set internally, the pulse rate can be externally varied or set with a front panel control, which in this case is three thumbwheel switches that can be adjusted from 10 to 10,000 steps per second. The length of travel of the transducer in either axis is controlled by the number of programmed output pulses that are preset into the thumbwheel switches. Each pulse gives 0.001 in. of transducer movement. If +49.999 is preset on the "X" controller and the "initiate" button pushed, the controller will output 49,999 pulses and a clockwise command to the "X" stepping motor. The motor will move the transducer 49.999 in. in a clockwise, or positive, direction and stop. These output pulses are automatically accelerated and decelerated by internal circuitry referred to as "ramps" and are adjustable.

The following controls are available on the front panel of each preset controller.

1) Power switch
2) Thumbwheel speed control (3-digit), 001 to 999 steps per sec (X10)
3) Preset pulse controls (5 digits and a sign), $\pm$00.000 to $\pm$99.999 in.
4) Initiate button (start pulse output to motor)
5) Cycle (Starts sequence of events which typically includes external direction control and the thumbwheel setting)
6) Jog (When pushed momentarily, the unit will output one pulse to the motor drive. When the button is held down, the transducer carriage will move until the button is released or the limit is reached.)
7) Reset (Used as a stop button, it will reset the counters and stop the pulse output)

C.1.2.3 Control Panel for X and Y Motors

A third chassis to control the interactions required between the X and Y controllers and motors has been designed and built. This is the primary control unit for the X- and Y-axes. This control unit has a switch to select one of four modes the scanner will operate in. These modes are manual, auto, computer auto, and computer programmed. They are explained in the following paragraphs.

Manual Mode: Each of the preset indexers will operate from its own individual control chassis when the primary controller is in the "Manual" mode.

Auto Mode: Select Scan X, Index Y, and place the mode switch in the "Auto" position. Press the "GO" button, and the X motor will run to its preset limit or manual limit and stop. The Y motor then indexes to its preset limit and stops, whereby the X motor then reverses direction and runs back to its original zero position. This scan and index motion will continue until a "STOP" button is pushed on the control panel or until a mechanical limit switch is closed. The motors will then stop until the operator initiates a new scan or the index direction can be reversed, and the cycle continues back overs its original path. An "INDEX REVERSAL" button will reverse the index direction after the present scan path is completed if it is desirable to repeat the scan in the reverse dirction.

If the Scan Y, Index X, is selected, then the motors will scan Y and index X in the same manner as described in the previous paragraph.

The speed controls on each preset indexer for each motor will be set manually when in the manual or auto mode.

Computer Mode - Auto: When the mode switch is placed in the computer-auto position, the operation of the X-Y scanner is essentially the same as manual-auto position, except the computer can now start and stop the scanner. The scan limits are still determined by the thumbwheel switches on the preset units.

Computer Mode - Programmed: Place the mode switch in the Computer Mode - Programmed position. The X-Y scanning mechanism can now be programmed from the computer for both scan length and index length by feeding digital words to the scanner from the computer. The rate of scan can also be fed to the scanner from the computer. The rate of scan can be programmed for each individual scan and index or it can be programmed for a fixed speed and left at that

speed for a complete scan over a test specimen or forging.

The sequence of events to operate the scanner from the computer in the programmed mode is as follows. We will assume that the test specimen will be sanned in the longitudinal axis (X) and indexed in the lateral axis (Y). Preload the X scan distance and direction in the computer. This can be any distance from 00.001 in. to 51.260 in., which is the maximum scan length in the X axis. Preload the rate of scan in the computer. This can be a speed between 0.01 and 9.99 in. per second. Preload the amount of index and direction required in the Y-axis. This would normally be approximately 00.025 in.; however, it can be any amount up to the maximum Y travel width, which is 34.850 in.

The execute command can now be given to the scanner by the computer and the scanner will move the programmed distance, then it will index the programmed distance. The scanner will now await the storage and processing of flaw data by the computer from the first scan before the computer gives it a scan return signal. This scan, index, and process data routine will be continued until the complete test specimen has been scanned. The computer, if programmed to do so, will then stop the scanner.

C.1.2.4 Encorders and Displays for X-and Y-Axes

A Data Tech heavy-duty industrial encoder that operates to the incremental mode is geared to the drive chains for both the X-and-Y axes. These encoders are geared in such a manner that for each 0.010 in. of transducer carriage movement, one pulse is sent to an up-down counter. This rotary motion that occurs in the encoder is digitized into high-level square waves in quadrature. These quadrature square waves are fed to a digital display.

The dual display is a Summit Engineering Model 8102B. Each of the channels contains a bi-directional counter and display designed to be used with an encoder operating from a numerical control system. The power supply for the encoder is contained in this display chassis. This display continuously monitors the transducer position in both the X-and-Y axes and displays it in 4 digits of position information to the nearest 0.010 in., i.e., if the transducer had moved 26 in. to the Y-axis, the display would read +26.00 in. A zero button is available so that the displays can be zeroed at any zero reference point.

Connectors on the rear of the displ[illegible] chassis output binary-coded decimal (BCD) logic levels that are fed to the computer so that the position of the transducer can be known continuously by the computer.

C.2 Manipulator Assembly

The manipulator assembly is shown in Figure 21 . This unit's function is to manipulate the transmitting and receiving transducers in three axes: vertical, rotation, and tilt. Each of these three functions can be accomplished manually with independent and separate controls, or they can be operated together as a system to give automatic transducer standoff distance and normality (90 deg) control.

Each of these three functions has a separate motor, motor control, encoder, and display that are discussed individually later. Position data from all three functions are fed by line drivers to the computer. The manipulator assembly that moves vertically and does not include the vertical stepping motor and the casting it is housed in weighs approximately 28 pounds.

The manipulator's vertical motion of 30 in. is in 0.001-in. increments. The maximum speed is approximately 3 in./sec. The transducer can be moved vertically up to 3.0 in. above the forging specimen by turning a control knob to the desired elevation and the motor will immediately move it to that position. If the distance of separation (DOS) circuit is turned on, the DOS can be maintained automatically over curved forgings. The DOS is displayed by 4 digits to the nearest 0.010 in.

The transducer can be rotated 180 deg in 0.45-deg increments at a maximum speed of 45 deg/sec and a minimum speed of 2.0 45 deg/sec. The transducer can also be moved one increment of 0.45 deg at a time. The transducer rotation position is displayed in 4 digits of information to the nearest 0.1 deg. The rate of transducer movement is adjustable from the control panel.

The transducer can be tilted 180 deg in 0.1 deg increments at a maximum speed of 210 deg/sec and a minimum speed of 20.0 deg/sec. The transducer can also be moved one increment of 0.1 deg at a time. The transducer tilt position is visually displayed in 4 digits to the nearest 0.1 deg. The rate of transducer tilt movement is adjustable from the control panel.

C.2.1 Control Method for Normalizing Transducer

The method selected for maintaining normalcy has one primary transmitting transducer and four receiving transducers located in a circle around it. Two of these receiving transducers are in one axis (Ø) and the other two are in the other axis (Ø). If the transmitter transducer puts out a pulse that is reflected from the surface back into two of the receiving transducers, these receivers each put out an energy pulse and these pulses are shaped and fed into gating circuits which control a stepping motor. The stepping motor runs one way or the other, depending on which receiving transducer receives the reflected pulse first. Two more receiving transducers and a stepping motor control the second axis in the same manner. The scanning-head transducer assembly has been configured to accommodate the four-ultrasonic-transducer normalizing system. This normalizing mode has been deleted from the system because it was too slow when scanning contoured surfaces. Normalizing is computer controlled.

C.2.2 Z-Axis Control on Manipulator

The vertical movement of the transducer is controlled by a dc stepping motor with 250 in. oz of torque geared to the vertical tube through a 21.6:1 gear reducer to give a rated torque of 2000 in. oz at the gear that drives the transducer tube. Each pulse to the stepping motor moves the transducer tube up or down 0.001 in. The vertical tube will move 30.240 in. inside the tank. The maximum speed will be adjustable from 0.10 to 3.00 in./sec.

The transducer can be moved vertically, either up or down, by setting thumbwheel switches between 00.000 and 30.240 in. and pushing a polarity and start button on the control panel. The transducer will then move to this preset position and stop. Ramp-up and ramp-down circuits are installed to prohibit abrupt starts and stops. The maximum speed can be adjusted by setting an internal potentiometer. The speed may then be varied externally with a knob on the control chassis up to the maximum internal speed adjustment. A jog switch will also move the transducer one step or continuously at a slow rate either up or down.

A rotary incremental encoder is attached to the shaft of the gear that drives the vertical Z tube. This gear moves the vertical Z tube ±4.320 in. per gear revolution. The encoder attached to this shaft will output 432 pulses for each shaft revolution. Therefore, the encoder display will read directly in 0.010-in. increments and will display from ±00.00 to ±30.24 in. The display is identical to the displays used for the X- and Y-position information. The Z-position information is fed to the computer in BCD logic, from a connector on the rear of the position display chassis. There are four digits of position information plus the polarity sign. These four digits convert to 16 BCD bits plus one bit for the polarity sign. This BCD logic is converted to binary logic by a converter card placed in the interface chassis in the computer. Differential line drivers are used to transfer the position data from the digital Z position display to the computer.

The vertical position display can be zeroed at any position or distance between the transducer and the forging being scanned. The transducer may be moved down until it touches the forging; then the display can be zeroed and as the transducer is moved vertically up from the forging, the display will read this separation distance directly in inches to the nearest 0.010 in.

The vertical motor (Z-axis) can presently be controlled from the manual control panel or by the distance-of-separation (DOS) circuit. The Z-axis is interfaced with the computer, which can control this axis.

C.2.3 Transducer Gimbal Mechanism (Old) - This mechanisms has been redesigned and is discussed in subsection 4.2.4.

A reproduction of the assembly drawing of the original transducer head mechanism is shown in Figure C1 . The mechanism attached to the lower end of the modified Automation Industries UM-743 manipulator. The head mechanism was designed and built by Convair.

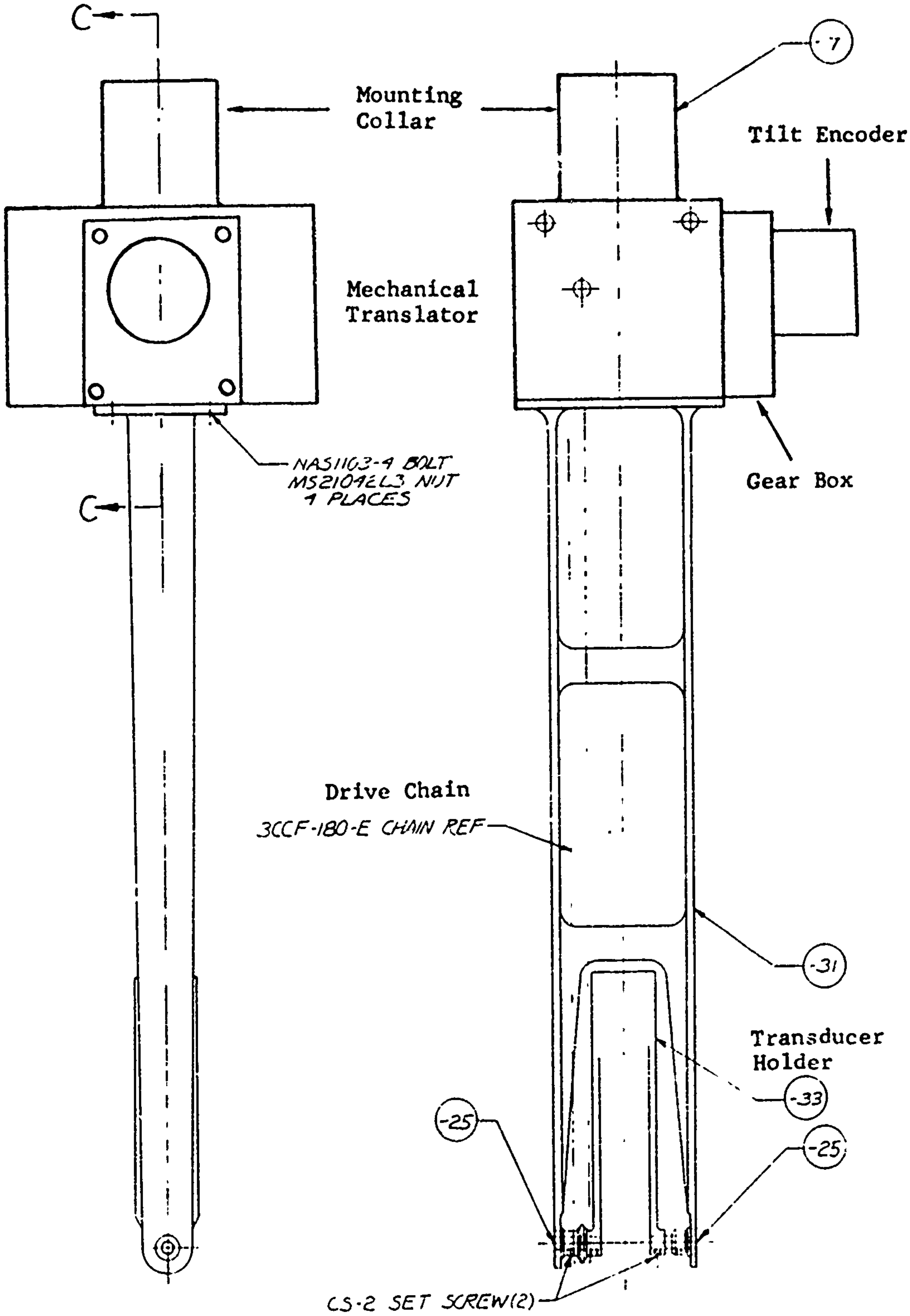


Figure C1. Assembly Drawing of Transducer Gimbal Mechanism

Thus was a mechanical analog which translated the ultrasonic transducer to keep the ultrasonic beam directed to the same point on the specimen while the ultrasonic transducer was tilted. This device worked for a specific distance of separation only.

C.2.3.1 Transducer Gimbal Modification

The original manipulator had two inherent problems associated with it. Problem No. 1 was the mechanical translation device that was housed in a 4" x 6" box on the manipulator shaft. This translation box made mechanical corrections to keep the transducer located directly beneath the indicated X and Y coordinate displays. This box only corrected properly up to ½" distance of separation between the transducer face and the top surface of the part being inspected. These coordinate corrections are now being handled by computer software for any distance of separation between the transducer face and the part. The translation box also had backlash problems that caused incorrect tilt-angle readings when the tilt direction was reversed. Due to the above problems encountered with the translation box it has been necessary to delete it and accomplish the transducer coordinate corrections with software.

The manipulator had a 12-inch extension between the translator box. The transducer was mounted on the lower end of this extension. A chain drive extended from the translation box to the transducer and drove it in the tilt axis. There was backlash in this chain drive mechanism. The new manipulator-extension design features the replacement of the chain drive with direct gear drives in order to avoid back lash error.

This new design is shown in Figure 21. This manipulator extension houses a standard-size transducer.

C.2.4 Tilt Motor, Controls, Encoder, and Display

The tilt motor and controls move the transducer through 180 deg of movement. A dc stepping motor with 50 in. oz of torque rotates a rod, geared to the transducer, inside the vertical manipulator tube. The motor and encoder are mounted on a casting at the top of the manipulator. The motor is geared to the rod through a clutch, pulley, and timing belt. There is an 8.8:1 gear reduction between the motor and the transducer; each pulse to the stepping motor moves the transducer 0.20 deg. Therefore, 880 motor pulses are required to move the transducer

through 180 deg. The speed of transducer movement is variable from 2 to 45 deg/sec. The maximum speed will only be limited by the mechanical linkage.

The control chassis for the tilt motor has all the controls, power, and logic required to operate the tilt motor electrically over the 180-deg range. A round control knob on the control panel is used to position the transducer to any desired angular position between 0 and 180 deg. The motor and transducer follow the angular position of the control knob. The rate of movement of the transducer is adjustable from a front panel control.

An incremental rotary encoder is attached through a gear to the tilt mechanism. This encoder outputs 1800 pulses for 180 deg of tilt. These pulses are counted and then displayed on a 4-digit display that will read the angle of tilt of the transducer from 000.0 to 180.0 deg.

Four digits of BCD logic tilt position information are available to the computer from a connector on the rear of the visual display. Line drivers are used to drive these 16 bits of position data to the computer. A data-ready pulse will also be available to the computer to indicate when the data can be sampled.

The power supply for the encoder is an internal unit inside the visual display chassis. The visual display is a bidirectional counter which indicates the titlt position at all times.

The tilt motor at present can be controlled from the manual control panel or by the computer. The necessary electronics have been installed to contrl the tilt motor from the computer, which has been programmed to drive the tilt motor.

C.2.5 Rotate Motor, Controls, Encoder, and Display

The rotate motor and controls move the transducer through 180 deg of movement in a horizontal manner. A dc stepping motor with 50 in. oz of torque rotates the vertical tube to which the transducers are attached. This motor is mounted on top of the manipulator and is geared to the vertical tube through a clutch and belt drive. There is a 4:1 gear reduction from the stepping motor gear and clutch to the gear around the vertical tube. The stepping motor makes two revolutions while the transducer rotates 180 deg. The stepping motor receives 400 pulses for the two revolutions. The angular movement of the transducer per stepping motor pulse is therefore 0.45 deg. The rate or speed of the stepping motor is adjustable from 10 to 1000 steps per second. Therefore, the minimum speed

of the transducer in angular movement is 4.5 deg/sec. The maximum speed is only limited by the mechanical linkage.

There is a control chassis for the rotate stepping motor. This controller has all the controls, power, and logic to operate the rotate motor electrically over its 180-deg range. By rotating switches to the desired angular position between 0 and 180 deg, the transducer will then move to this position and stop. The speed of transducer movement is adjustable from a front panel control.

An incremental rotary encoder is geared through a rubber timing belt to a large gear around the vertical tube. The gear relationship between the vertical tube and the shaft encoder is an 8:1 increase. The encoder turns four times while the vertical tube and transducer move 180 deg. The encoder has an output of 450 quadrature pulses per revolution for a total output of 1800 pulses while the transducer moves the 180 deg. These pulses are displayed on a 4-digit visual display that reads from 000.0 to 180.0 deg with an accuracy of ±0.1 deg.

The power supply for the encoder is an internal unit inside the visual-display chassis. The display is a bidirectional counter and will count either up or down and indicate the rotation direction with a polarity sign.

Four digits of BCD logic are available to the computer on a connector from the rear of the visual display. Line drivers are used to drive these 16 bits of data to the computer. A data-ready pulse is also available to the computer to indicate when the data can be sampled.

The rotate motor can be controlled from the manual control panel or by the computer. The necessary electronics have been installed to contrl the rotate motor from the computer which has been programmed to drive the rotate motor.

APPENDIX D

COMPUTER HARDWARE

This section describes the peripheral devices, module utilization, and the modification required for proper system operation.

D.1 Computer Peripheral Devices

Figure 29 is a block diagram showing the peripheral devices used in the system. With the exception of the BB11-CTN unit all the devices are standard off-the-shelf Digital Equipment Corporation (DEC) modules.

D.1.1 Analog-to-Digital and Digital-to-Analog Subsystems

The AD11 is a flexible, multichannel analog data acquisition system. This system has 8 analog input channels, expandable to 32; programmable input range selector; control; and a sample and hold amplifier to reduce the conversion aperture to 100 nanosecond.

The AA11 is a high performance multichannel digital-to-analog converter. The AA11-D controls four 12-bit digital-to-analog converters that have a maximum update rate of 50K Hz per channel.

D.1.2 Digital Input/Output Subsystems

The DD11 peripheral mounting panel is a pre-wired system unit designed for mounting up to four small peripheral controller interfaces. The BB11-H DEC kit when fully configured provides four input channels and four output channels. They are pre-wired for logic and UNIBUS signals and for power. Figure D1 shows the module utilization of DD11.

DD11 UNIT	ROW A	ROW B	ROW C–F
1	M920 UNIBUS JUMPER (rows A–B)		NOT USED
2			M7860 GENERAL DEVICE INTERFACE IV 400 ULTRASONIC FLAWS, AMPLITUDE & SYNC INPUT ADDR 165000 OUTPUT NOT USED
3	POWER INPUT		M7860 DR11-C GENERAL DEVICE INTERFACE IV 310 Y POSITION INPUT ADDR 167760 Y PRESET OUTPUT
4	M920 UNIBUS JUMPER (rows A–B)		M7860 DR11-C GENERAL DEVICE INTERFACE IV 300 X POSITION INPUT ADDR 167770 X PRESET OUTPUT

Figure D1. Module Utilization of the DD11 System Unit

D.1.2.1 General Device Interfaces

The DR11-C general device interface is a quad height module that plugs into either a small peripheral slot in the processor or into one of four slots in a DD11 small peripheral mounting panel.

This system contains three DR11-C modules. The DR11-C contains three functional sections - a 16-bit buffered output register, a 16-bit data input circuit, and a 2-channel flag and interrupt control.

D.1.2.2 DEC Kit 11-H I/O Interface

The BB11-H DEC kit is capable of reading four 16-bit words from a peripheral device or writing four 16-bit words or eight 8-bit byte to peripheral device. Each input word is supplied with interrupt capability. The module utilization layouts of the two BB11-H DEC kits for this system are shown in Figures D2 and D3 .

D.1.3 System Clock

The features of the KW11-P programmable real-time clock are: four clock rates, program selectable and crystal-controlled clock for accuracy, three modes of operation, two external inputs, and interrupt at the line frequency.

D.1.4 Hi-Speed Reader/Punch Subsystem

The PC11 high speed reader and punch subsystem is capable of reading eight-hole unoiled perforated paper tape at 300 characters per second, and punching tape at 50 characters per second. The system consists of a paper tape reader/punch, and control module.

D.1.5 Graphic Display Terminal

The display device is a Tektronix 4010 cathode-ray storage tube. The viewing screen is 7.5 inches by 5.6 inches and has the capacity of 35 lines by 72 characters per line. For graphic, the unit has a resolution of 1024 addressable point in both X and Y axes. This unit uses a DL11-E interface unit setup for a transfer rate of 9600 BAUD.

ROW

SLOT	F	E	D	C	B	A
1	M1500 BUS GATE MODULE	M1501 BUS INPUT 164040:R POS	M1502 BUS OUTPUT 164030: X SPEED		M920 UNIBUS JUMPER	
2	M7821 INTR CONTROL IV 330	M1501 BUS INPUT 164042: Z POS	M1502 BUS OUTPUT 164032: Y SPEED			
3	M1500 BUS GATE MODULE	M1501 BUS INPUT 164044: T POS	M1502 BUS OUTPUT 164034: ATTEN			POWER INPUT
4	M7821 INTR CONTROL IV 320	M1501 BUS INPUT 164046: FLAGS	M1502 BUS OUTPUT 164036: MODE B		M920 UNIBUS JUMPER	

Figure D2. Module Utilization of BB11-H Digital I/O System No. 1

SLOT	ROW F	ROW E	ROW D	ROW C	ROW B	ROW A
1	M1500 BUS GATE MODULE	M1501 BUS INPUT 164060	M		UNIBUS JUMPER	
2			M1502 BUS OUTPUT 164052: Z PRESET POSITION		M105 BUS ADDR MODULE	
3			M1502 BUS OUTPUT 164054: T PRESET POSITION		M105 BUS ADDR MODULE	POWER INPUT
4			M1502 BUS OUTPUT 164056: R PRESET POSITION		M930 UNIBUS TERMINATOR	

Figure D3. Module Utilization of BB11-H Digital I/O System No. 2

D.1.6 Dual Counter Subsystem

This system is used to obtain pulse length and event counts in a form that can be input to the computer. This is done by a modified DEC M795 word count and bus address unit. A dual counter unit consists of four modified M795 units and two M105 address selector units. Figure D4 shows the module utilization of BB11-CTS Unit.

D.1.7 Signal Conditioning Subsystems

All high speed digital signals are transmitted by differential line-drivers and received by differential line-receivers to preserve effective waveshape. Output buffers were required on the DR11-C and M1502 bus output devices due to loading effect of the long cable going to scanner control console. Figure D5 and D6 show the module utilization for the BB11s.

D.1.8 Interface Address Assignments

Table D1 is a complete list of the hardwired address assignments that were being used at the completion of Phase I.

D.2 Interface Development

This section describes the line driver/receiver modification and the dual counter subsystem that were designed and fabricated by General Dynamics.

D.2.1 Line Driver and Receivers

The DEC line receiver (Y90) and line driver (Y91) schematics are shown in Figures D7 and D8.

The line driver/receiver setup had to be modified to prevent degradation of high-speed signals. Table D2 lists the signals and their leading edge rise times before and after modification.

ROW

	F	E	D	C	B	A
SLOT 1		M105 ADDR SELECT 164000	MODIFIED M795 REG A: FLAW DEPTH REG B: THICKNESS		UNIBUS INPUT	
2	M113 NAND GATES		MODIFIED M795 REG C: SEPARATION REG D: -SCAN DISC #1			
3		M105 ADDR SEL 164010	MODIFIED M795 REG E: -SCAN DISC #2 REG F: -SCAN DISC #3			POWER INPUT
4	M405 10 MHz	M927 INPUT COND	MODIFIED M795 REG G: -SCAN DISC #4 REG H: NOT USED		M920 UNIBUS JUMPER	

Figure D4. Module Utilization of BB-11-CTS System

ROW

SLOT	F	E	D	C	B	A
1	Y91 DRVR Y PRESET INVERTED	Y91 DRVR Y PRESET INVERTED	Y91 DRVR X PRESET INVERTED	Y91 DRVR X PRESET INVERTED	M920 UNIBUS JUMPER	
2	M927 CONN R POS OUTQ TO M1501	M927 CONN Y PRESET INPUT	M927 CONN X PRESET INPUT	Y90 RCVR R POS		
3	M927 CONN Y POS OUT TO DR11 #3	Y90 RCVR Y POS/ R POS		Y90 RCVR Y POS		POWER INPUT
4	M927 CONN X POS OUT	Y90 RCVR X POS/ Y POS		Y90 RCVR X POS	UNIBUS OUTPUT	

Figure D5. Module Utilization of Line Driver/Receiver System Unit No. 1

ROW

<table>
<tr><th>F</th><th>E</th><th>D</th><th>C</th><th>B</th><th>A</th><th>SLOT</th></tr>
<tr><td>M927 CONN
ATTEN INPUT
FROM 1502</td><td>M927 CONN
OUTPUT TO
COUNTERS</td><td>M927 CONN
INPUT FROM
Y SPEED</td><td>M927 CONN
INPUT FROM
X SPEED</td><td colspan="2">M920
UNIBUS JUMPER</td><td>1</td></tr>
<tr><td>M927 CONN
FLAGS OUT
TO M1501</td><td>Y91 DRVR
ATTEN OUT</td><td>Y91 DRVR
X SPEED OUT</td><td>Y90 RCVR
GATES & CNTS
(MODIFIED)</td><td></td><td></td><td>2</td></tr>
<tr><td>M927 CONN
T POS OUT
TO M1501</td><td>Y90 RCVR
FLAGS AND
GATES
(MODIFIED)</td><td>Y91 DRVR
X/Y SPEED
OUT</td><td>Y90 RCVR
T POSITION</td><td></td><td>POWER
INPUT</td><td>3</td></tr>
<tr><td>M927CONN
Z POS OUT
TO M1501</td><td>Y90 RCVR
Z/T POSI-
TION</td><td>Y91 DRVR
Y SPEED
OUT</td><td>Y90 RCVR
Z POSITION</td><td colspan="2">M920
UNIBUS JUMPER</td><td>4</td></tr>
</table>

Figure D6. Module Utilization of Line Driver/Receiver
System Unit No. 2

TABLE D1

PERIPHERAL DEVICE ADDRESS ASSIGNMENTS

DEVICE	ADDRESS	V.A.*/(CHANEL)	COMMENTS
Dual Counter #1	164000		Depth (FG # 2)
	164002		Thickness (FG # 4)
Dual Counter #2	164004		DOS (FG #1)
	164006		Delta Counter #1
Dual Counter #3	164010		Delta Counter #2
	164012		Delta Counter #3
Dual Counter #4	164014		Delta Counter #4
	164016		(FG # 3)
Bus Input (M1501)	164020	334	Rotate
	164022		Z
	164024	336	Tilt
	164026	330	Flags and Sync
Bus Output (M1502)	164030		X Speed
	164032		Y Speed
	164034		Attenuator
Bus Input (M1501)	164040		Rotate, Tilt, Z Flags
Bus Output (M1502)	164052		Rotate
	164054		Tilt
	164056		Z
DR11-C	165000	400	Control & Status
	165002		Output (not used)
	165004		Ultrasonic Input
DR11-C	167760	310	Control & Status
	167762		X Output
	167764		X Input
DR11-C	167770	300	Control & Status
	167772		Y Output
	167774		Y Input
D/A Converter (AA11)	176760	(1)	Flaw Gate Width
A/D Converter (AD11)	176770		Control & Status
	176772		A/D Buffer
		0	Reflection Flaw Ampl.
		(1)	Shear Flaw Ampl
		(2)	Top Surface
		(3)	FG # 3 Amplitude
		(4)	FG # 4 Amplitude

TABLE D1 (CONT'D)

PERIPHERAL DEVICE ADDRESS ASSIGNMENTS

DEVICE	ADDRESS	V.A.*/(CHANEL)	COMMENTS
KW11-D	172540	104	Programmable Clock
M782YCD	173110		Bootstrap Loader
DL11-E	175610	3703	Tektronix 4010
PC11	177550	70	Paper Tape R/P
Teletype	177560	60	System Console

* Vector Address

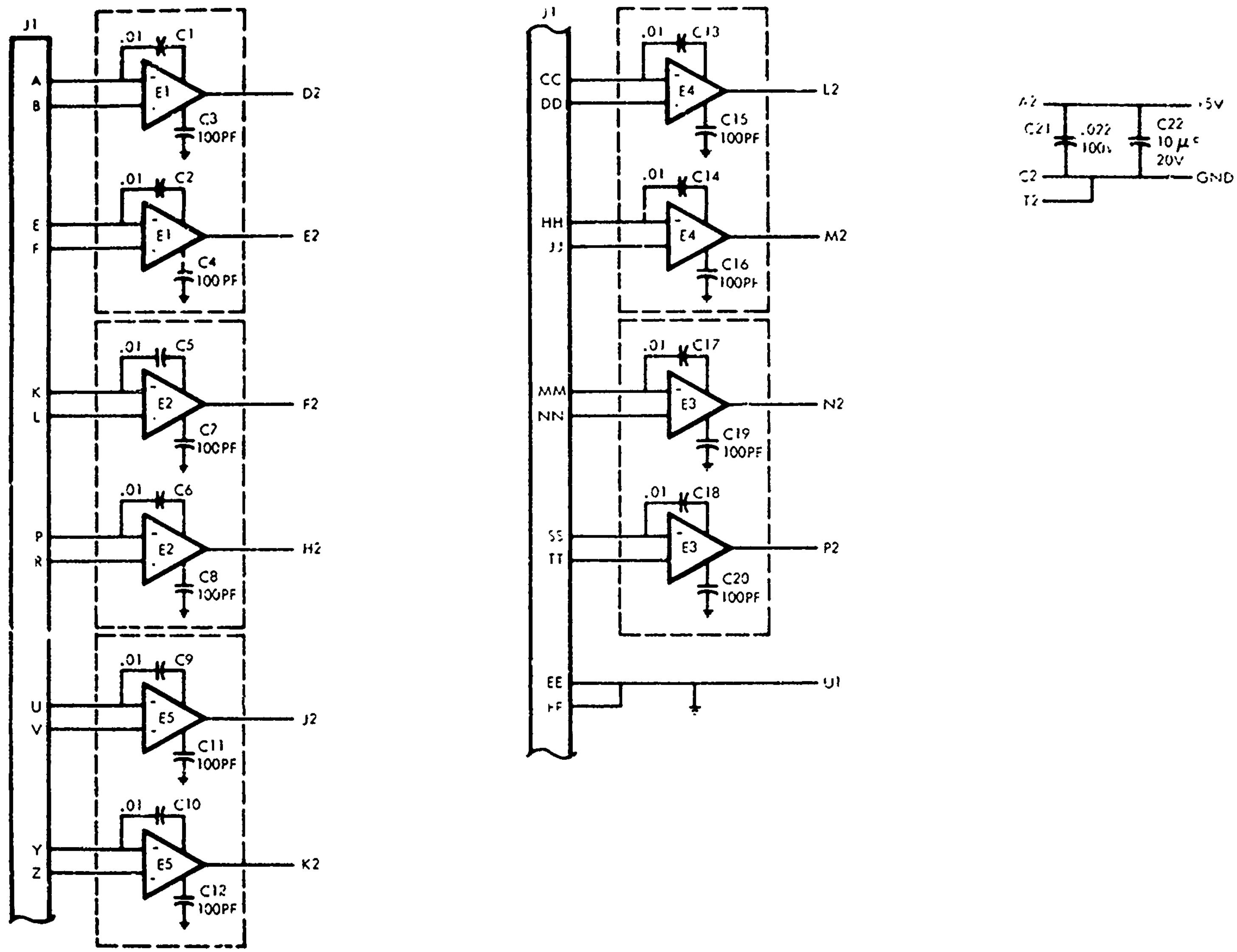


Figure D7. Y90 Line Receiver Schematic

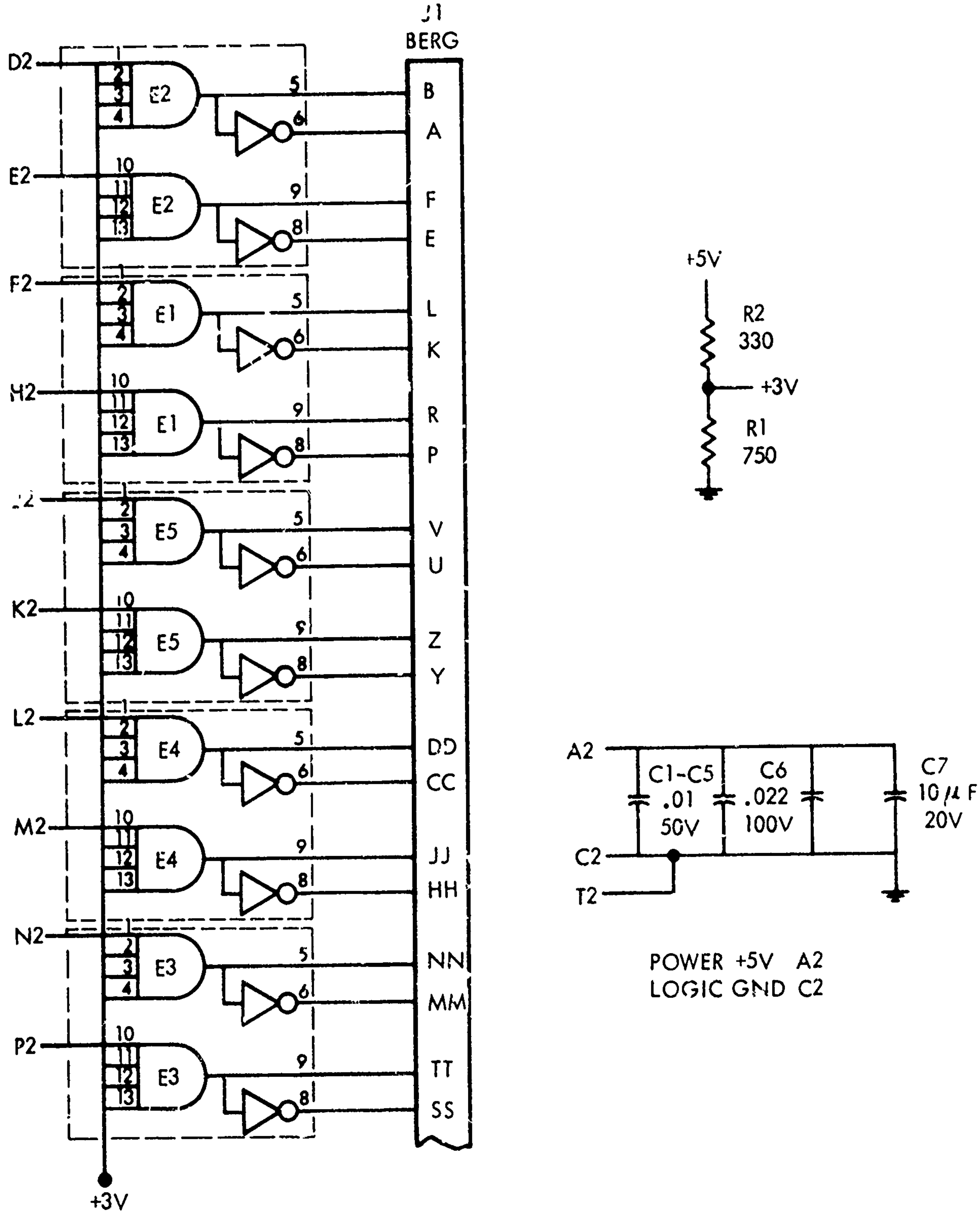


Figure D8 Y91 Line Driver Schematic

TABLE D2

SIGNALS THAT REQUIRED LINE-RECEIVER MODIFICATION

Signal Name	Standard Driver/Receiver Rise Time	Modified Receiver Rise Time
Clear Counters	150 Nsec	40 Nsec
Flaw Depth Gate	200 Nsec	40 Nsec
Thickness Gate	180 Nsec	40 Nsec
Separation Gate	180 Nsec	40 Nsec

The modification to the line receivers was required because the leading-edge (positive-going) rise time was too great. This was found to be the result of the design of the DM8820A output, which is a wired OR circuit. To obtain the required operating speed, the response capacitors (100 PF) were removed and a 220Ω, 1/4-watt pullup resistor was added to the output. Figure D9 shows the modified line-driver/receiver circuit.

D.2.2 Dual Counter Subsystem

The dual counter system comprises four modified DEC M795 modules, two M105 address selector modules, one M405 10-MHz clock module, and one M113 NAND gate module installed in a BB11 prewired system unit as shown in Figure D4. The dual counter BB11 was wired by General Dynamics.

D.2.3 M795 Unit Modification

The DEC standard M795 word-count and bus-address unit was modified to operate as two synchronous, 16-bit binary counters. Figure D10 is a schematic of the M795 incorporating the following modifications:

1) Register A

   a. Circuit board etch cut between IC E3 Pin 6 and IC E9 Pin 6.

   b. Circuit board etch cut between ICE11 Pin 9 and ICE9 Pin 5.

   c. Circuit board etch cut between Pins 1 and 2 of IC E3.

   d. Jumper added between Pin 5 and Pin 6 of IC E9.

   e. Jumper added between Pin 2 and Pin 13 of IC E3.

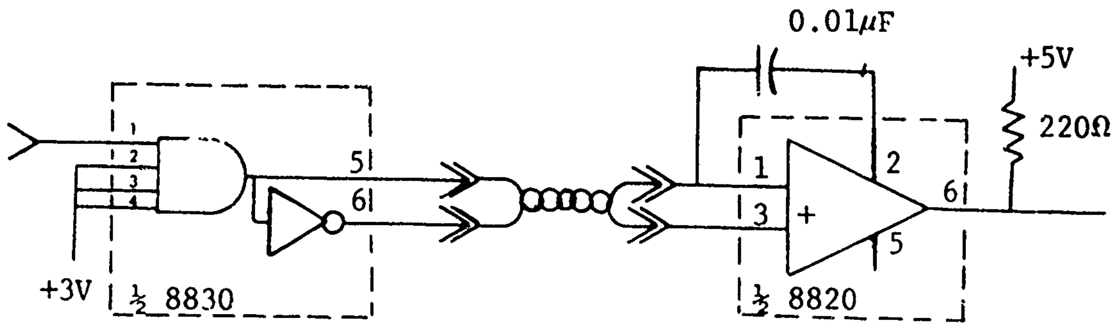


Figure D9. Modified Line Driver/Receiver Setup

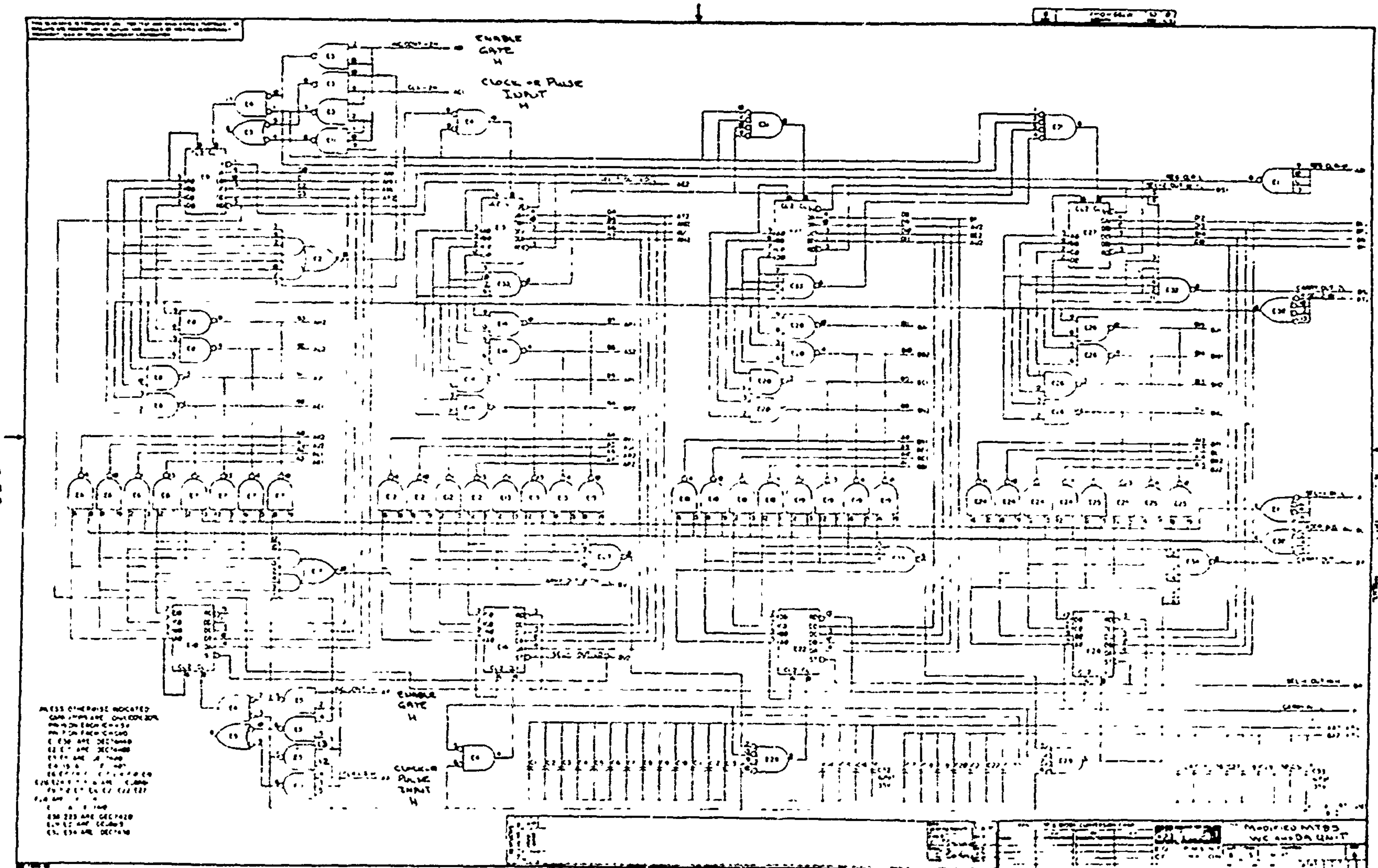


Figure D10. Dual Counter (Modified M795) Schematic

2) <u>Register B</u>

a. Circuit board etch cut between IC E5 Pin 8 and IC E10 Pin 6.

b. Circuit board etch cut between IC E11 Pin 5 and IC E10 Pin 5.

c. Circuit board etch cut between Pin 12 and Pin 13 of IC E5.

d. Jumper added between Pin 5 and Pin 6 of IC E10.

e. Jumper added between Pin 13 and Pin 2 of IC E5.

These modifications have been incorporated in the four M795 units now installed in the dual counter interface unit.

D.2.4 System Interconnection

The interconnections between the line driver/receiver units, the scanner control unit, and the ultrasonic unit are shown in the system harness diagram (see Figure D11). The interconnections between the line driver/receiver units and the computer interface units are shown in the extension box harness diagram, (see Figure D12).

D.2.5 System Modification for Ultrasonic System

The system was modified by the addition of a new receptacle for the ultrasonic system utilizing the existing input cable and adding two line drivers for reset and early sync signals. A jumper cable was added to the rear of the connector to allow use of existing ultrasonic signals to utilize the present input devices.

New signals were wired to J_2 of a new DR11C for inputs to the computer and one output from the CSR to provide the early sync for the ultrasonics. See Figure D1.

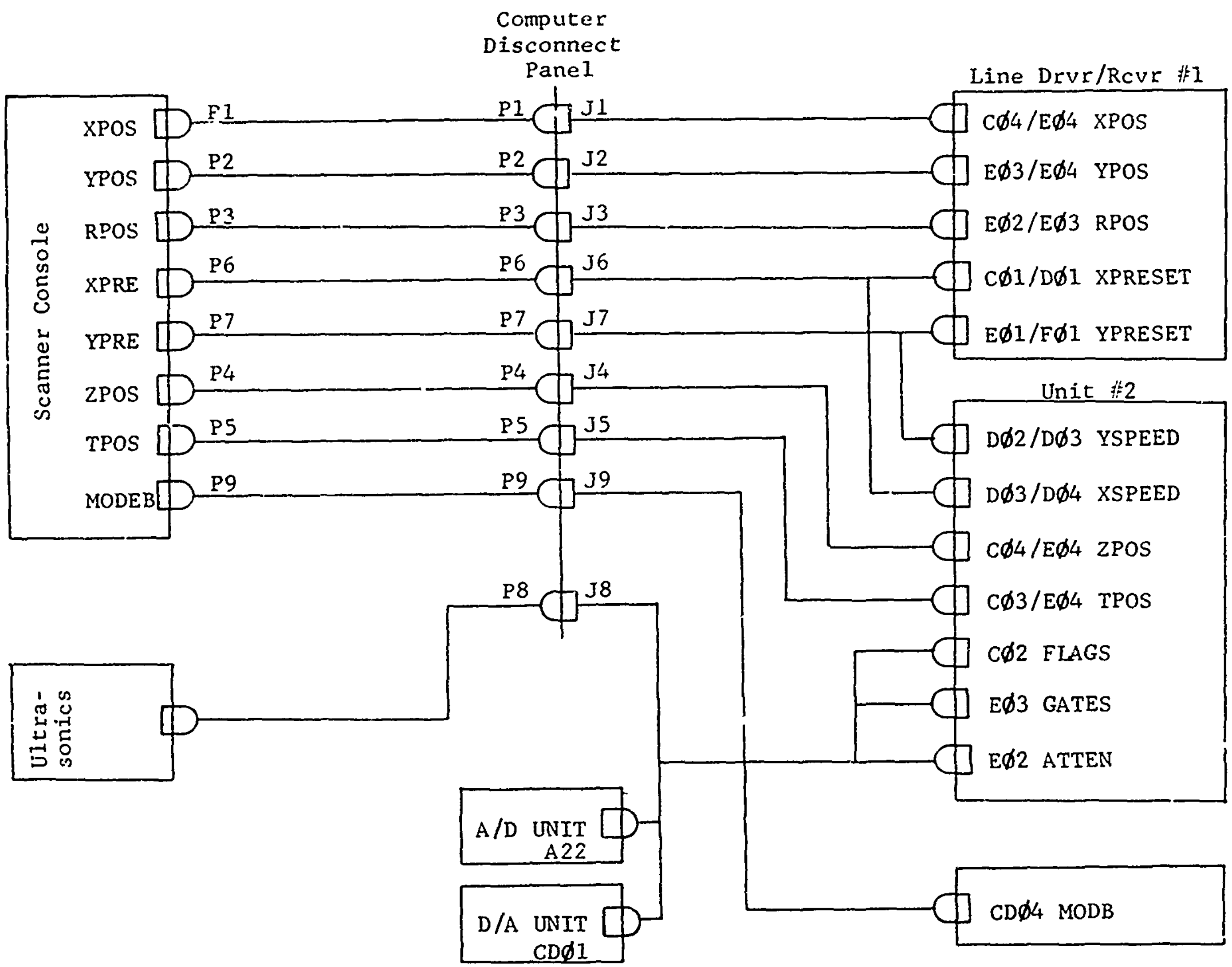


Figure D11. Computer System Interconnect Harness Diagram

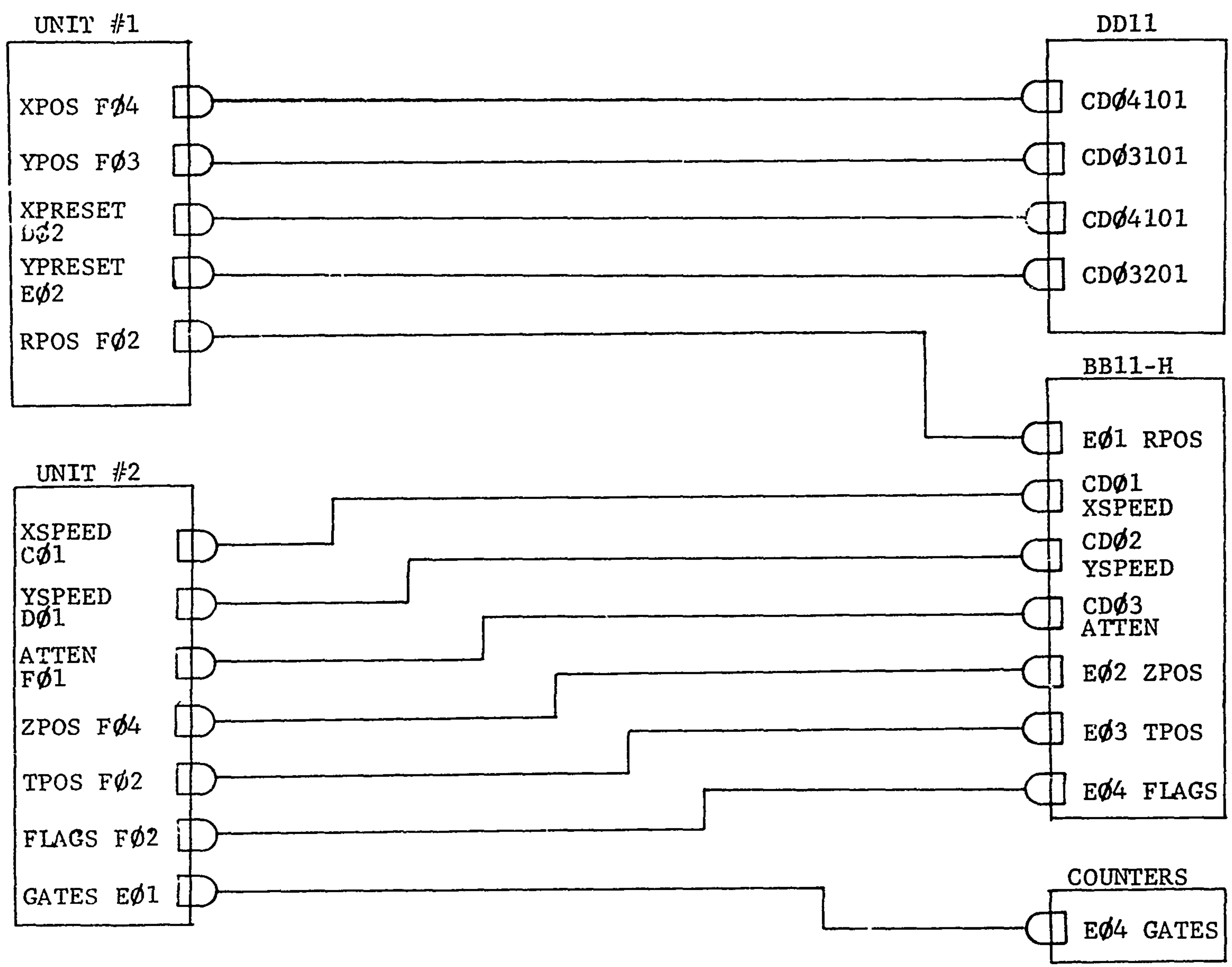


Figure D12. Interface Extension Box Interconnect Harness Diagrams

APPENDIX E

COMPUTER SOFTWARE

This section describes the software that is used to control the scanner, acquire the ultrasonic data, and process and display the data. Approximately 40% of the software for the AUISCM' program came from the previous contract and was modified to the needs of the project. Approximately 99% of the software for the 'POSTPR' program is newly developed.

E.1 Data Acquisition Programs

The program 'AUISCM' has five functions or run modes. They are listed and briefly described below:

INITIAL	=	Allocate new disk and then take data
DATA	=	Perform a scan and store data
LIST	=	The data runs stored on disk and the amount of disk space used are listed
DELETE	=	The last data run stored is deleted from the disk
EXIT	=	The linkage to the disk is released and program exits to monitor.

The 'AUISCM' program operated in reflection mode and contains eight overlays described below.

E.1.1 Resident Main

The resident for 'AUISCM' contains the communication area (commons) and calls all other overlays. It occupies 6K of the available 24K of memory space.

E.1.2 Overlay Ø

This overlay handles the selection of the run mode and FDF file initialization. It includes routines for the execution of the three run modes LIST, DELETE, and EXIT.

E.1.3 Overlay 1 - Overlay 7

These overlays perform the function of the data acquisition phase. Overlay 1 and overlay 2 are preparatory in nature.

Overlay 1 allows the operator to change the input parameters shown in Figure B4 and sets up the various commons. It also calculates the distance from the transducer to the back-up plate by returning the five axis scanner to the zero point where a series of pulses are examined.

Overlay 2 draws the grid, labels the axis, and writes the identification information.

Overlay 3 performs the Zone Ø data acquisition function. The part is placed in an imaginary rectangle whose size is predetermined by operator inputs. The rectangle is then scanned and boundary points (one X-point and two Y-points) are saved for use in the Zone N scan. It contains elements for scanner control and real-time data display.

Overlay 4 performs the Zone N scan for acquisition of flaw data by using the boundary points provided by the Zone Ø scan. It contains the elements for real-time data transfer, scanner control, and near real-time data display for top surface and suspect flaw data.

Overlay 5 performs vector-radius scans of areas designated by the operator. These areas are registered by moving the transducer to the starting and stopping points where the computer reads the encoder positions. This action is performed only one time. The next time the part is scanned the computer will have these points stored for continuous use. This overlay also contains the elements for real-time data transfer and near real-time data display.

Overlay 6 performs the scanning necessary to inspect curved-radius areas. The operator must register each point to be inspected with the computer. This overlay contains the elements for real-time data transfer and near real-time data display.

Overlay 7 performs the scanning necessary to inspect pocket areas similar to those shown on the F-16 Isothermal Bulkhead. These procedures are a combination of Overlay 5 and Overlay 6. This overlay contains the elements for real-time data transfer and scanner control.

E.1.4 Disk Usage

The DOS monitor and all user routines and subroutines reside on disk unit 0 (DK0). The data file is 4790 blocks in length and reside on disk 1 (DK1). Each block has 256 words for a total of 1.2 million 16 bit words. The blocks are written out sequentially during the data run.

The format for each data run consists of two header blocks that contain all the pertinent information relating to setup and the number of blocks used for data storage. These blocks are followed by the data blocks. A special bit pattern is written after each data acquisition run to mark the end of the used portion of the disk. Table E1 describes the formats of the data blocks.

Blocks 4401 to 4500 on the data file (DK1) are used to store identification information, normals for planar and radius regions, boundary points, points for curved radius areas, and points to scan pocket areas in the format described in Table E2 .

TABLE E1

DATA STORAGE FOR EACH ZONE TYPE

	Zone N	Radius	Curved Radius
1	Zone Number	Zone Number	Zone Number
2	Tilt Position	Tilt Position	Tilt Position
3	Rotate Position	Rotate Position	Rotate Position
4	Index Position	Index Position	Index Position
5	Flag Word	Flag Word	Scan Position
6	Scan Position	Scan Position	Z Position
7	Separation	Separation	Flag Word
8	Thickness	Flaw Depth	Separation
9	Flaw Depth	Index Position	Thickness
10	Flag Word	Flag Word	Flaw Depth
11	Scan Position	Scan Position	Tilt Position
12	Separation	Separation	Rotate Position
13	Thickness	Flaw Depth	Index Position
14	Flaw Depth	.	Scan Position
15		.	Z Position
16		.	Flag Word
17		.	Separation
18		.	Thickness
19		.	Flaw Depth
.		.	.
.		.	.
.		.	.
.		.	.
.		.	.
.		.	.
.		.	.
.		.	.
256.	Link Word	Link Word	Link Word
	Data Record		

TABLE E2

DATA STORAGE FOR BOUNDARY INFORMATION

Block I - 255 Words

(1) Part Name - 10 words (20 characters)
(2) Side Name - 4 words (8 characters)
(3) Scan type - 1 word

(a) 0 = Zone N scan only
(b) 1 = Zone N and radius scans
(c) 2 = Zone N and curved-radius scans
(d) 3 = Zone N, radius, and curved-radius scans
(e) 4 = Zone N and pocket scans
(f) 5 = Zone N, radius, and pocket scans
(g) 6 = Zone N, curved-radius, and pocket scans
(h) 7 = Zone N, radius, curved-radius, and pocket scans

(4) Radius scan end points - 240 words (60 sets of 4 each - maximum)

(a) X starting position
(b) Y starting position
(c) X stopping position
(d) Y stopping position

Block II - 255 words (maximum of 51 normals)

(1) Normals for Zone N scanning

(a) X-point - 1 word
(b) Y-point - 1 word
(c) Z-point - 1 word
(d) rotate angle - 1 word
(e) tilt angle - 1 word

(2) Normals for vector-radius scanning

(a) X-point - 1 word (multiplied by -1 to signify starting of radius normals
(b) Y-point - 1 word
(c) Z-point - 1 word
(d) rotate angle - 1 word
(e) tilt angle - 1 word

Block III - Block XXX

(1) Boundary points computed in Zone 0 scanning

(a) X-scan line - 1 word
(b) Y starting point - 1 word
(c) Y stopping point - 1 word

(2) Points necessary to scan curved radius areas

(a) X-position
(b) Y-position
(c) Z-position
(d) Rotate angle
(e) Tilt angle

(3) Points necessary to scan pocket areas

(a) Points necessary to vector scan radius 1

(1) X-starting position - 1 word
(2) Y-starting position - 1 word
(3) X-stopping position - 1 word
(4) Y-stopping position - 1 word
(5) Rotate position - 1 word
(6) Tilt Position - 1 word

(b) Points necessary to scan curved radius 1 in pocket

(1) X-position - 1 word
(2) Y-position - 1 word
(3) Rotate position - 1 word
(4) Tilt position - 1 word
(5) Points (1-4) are repeated for each point to be scanned in the curved radius of pocket

(c) Points for (a) and (b) are repeated for each vector radius and curved radius of the pocket

E.1.5 Data Compression

Since there are large amounts of data to be taken for any given part, efficient methods of data taking and compression must be developed. In the algorithm used in a previous contract, data were taken only over an area with a flaw signal above some set threshold level and eight (16 bits) words were recorded for every pulse, X,Y,Z,θ,Ø, Δf (flaw amplitude), df (flaw depth), and T (component thickness). At a scan rate of 3" per second and a pulse rate of 500 per second, eight words will be recorded every 0.006 inch over the flawed area. The newly developed algorithm, used in conjunction with the zone scanning, records only five words when a flaw amplitude is above some threshold level. The five words will be for Y, Δf, df, T, and a flag word which contains the following information: (1) number of flaws (4 bits), (2) back-up plate bit used to sense loss or discovery of the back-up plate (used in zone-Ø scanning), (3) amplitude of first flaw (4 bits), (4) over-the-part bit, set at the first discriminatory level, and (5) top-surface-reflection bit. The values of X, θ, Ø, and Z are recorded as constants for each scan line. In addition the pulse rate will be decreased and controlled by the computer so data will be taken over a flawed area at some selected but constant spacing such as 0.10 inch to reduce the total number of samples taken and the memory storage space required.

E.2 Post Processing Programs

The program 'POSTPR' has 12 different options for use shown in Figure B6 . The options are run under two different modes. 'Area filter' mode allows the operator to specify a particular section of the part to be 'blown-up'. This mode gives a close-up look at questionable flaw areas. The default mode allows the operator to look at a total view of the part. Both of these modes may be run in 'report' form,which gives a listing of recorded data.

E.2.1 Resident Main

The resident for 'POSTPR' contains the communication area (commons) and calls all other overlays. It occupies 4K of the available 24K of memory space.

E.2.2 Ovinit

This overlay handles the selection of the various modes and options available for processing flaw data. Other functions included in this overlay are preparatory in nature.

E.2 3 Ovdraw

This overlay draws the gird, labels the axis, and writes the identification information. It also plots the outline of the part using the boundary points computed in Zone Ø scanning.

E.2.4 Ovplot

This overlay enables the operator to display previously recorded data. Features include variable size grid limits, selection of data based on its depth, amplitude, condition of the back surface, consecutive pulses, and adjacent scan lines. These features are referred to as 'filters.' The results of these filters may be displayed on the 4010 scope as flaw locations on the point outline, or they may be listed in report form.

E.3 Flow Diagrams

This section describes and charts the flow diagrams.

E.3.1 Resident Main for Zone Scanning

The resident main is not an overlay, therefore it and all routines it calls reside in core at all times. The actual overlays are brought into core by the routine LINK. The parameter run mode, set in overlay Ø, is used to select which overlay is called. After each run mode is executed, control is returned to the resident and then to overlay Ø.

E.3.2 Overlay Ø

This overlay performs much of the setup and operator I/O for the program.

The first operation performed is the selection of one of five run modes. 'INITIAL' run mode allows a new disk to have the data file (FDF.01) to be allocated on an old data disk to be initialized.

For run modes 'LIST' and 'DELETE' these functions are performed within the overlay. Control is then returned to the top of the overlay. For run mode 'EXIT', the file linkage is released and the program is terminated. For run modes 'INITIAL' and 'DATA' the specific run number must be entered. This allows a search to be initiated for the start block number. In the case of 'INITIAL', no checking is performed and the first block of the disk file is designated the start block. In the case of 'DATA', the entered run number must not appear before the end of data mark is found, if it does, the run number can be re-entered. If the run number is not re-entered, the run mode is set to 'LIST' and the run numbers are listed.

After the end of data mark is located, the header blocks of the previous run are used as the header blocks of the new data run. These blocks can be changed in overlay 1 if required. The flow diagram is shown in Figure E1.

E.3.3 Data Acquistion Control Module

The data acquisition control module (CNTZNN) controls the flow of processing for the data acquisition task. Interface is made with elements of the scanner control module (SCNMOD), the data acquisition interrupt module (ACQZN), and the data storage module (DSBUF).

After buffer status has been set and scanner initialization has been completed, a signal, called early sync, is sent to the ultrasonic unit to issue a pulse and take data. The routine then waits for a signal, called computer sync, so that data may be analyzed and saved by the Data Acquisition Interrupt Control Module. Control is then returned to CNTZNN and preparations are made to issue the next ultrasonic pulse. The flow diagram for this routine is shown in Figure E2.

E.3.4 Data Acquisition-Interrupt Control Module for Zone N Scanning

The Data Acquisition-Interrupt Control Module (ACQZN) processes the interrupt generated at the end of each ultrasonic

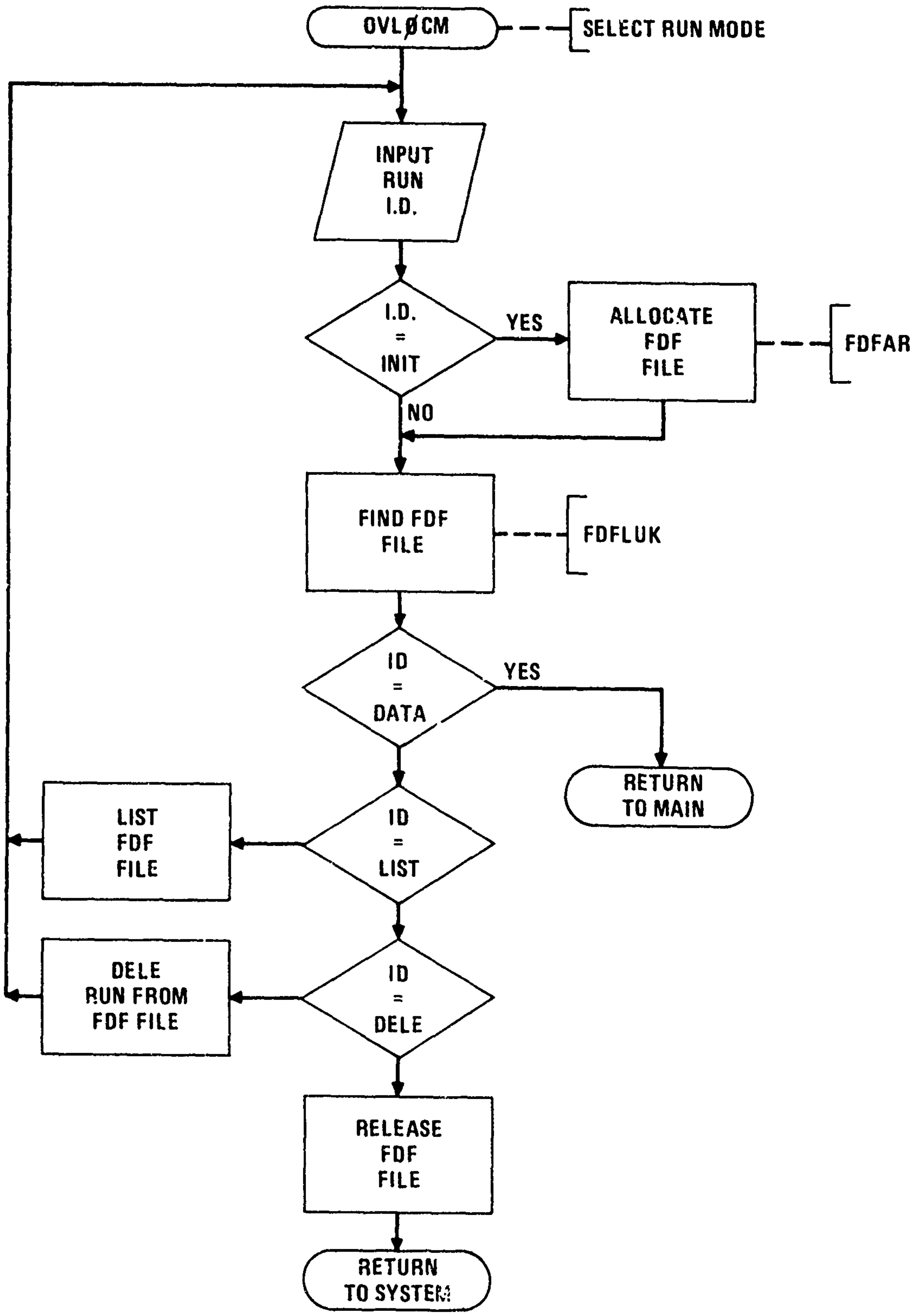


Figure E1. Flow Diagram For Overlay Ø

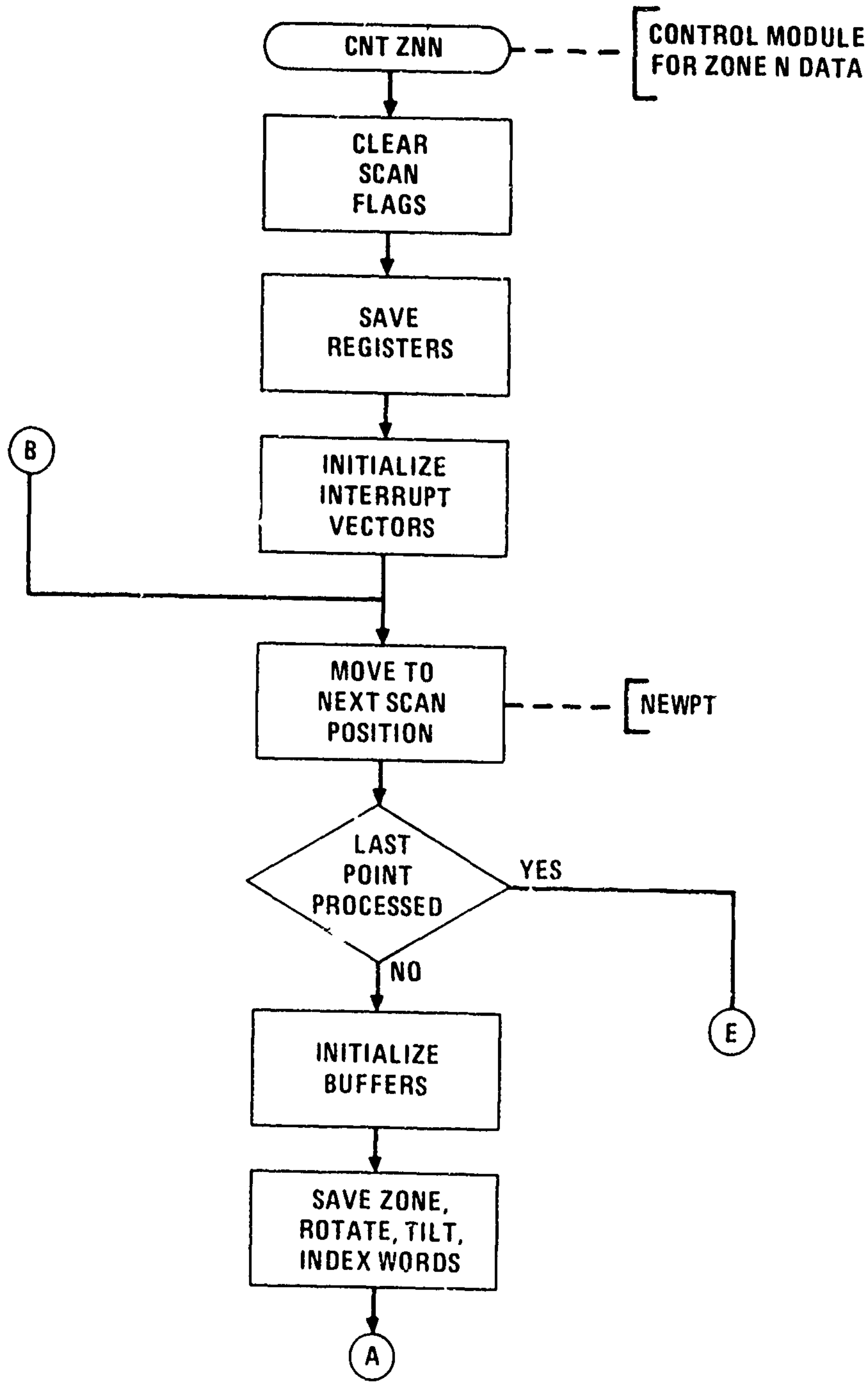


Figure E2. Flow Diagram For Data Acquisition Control Module

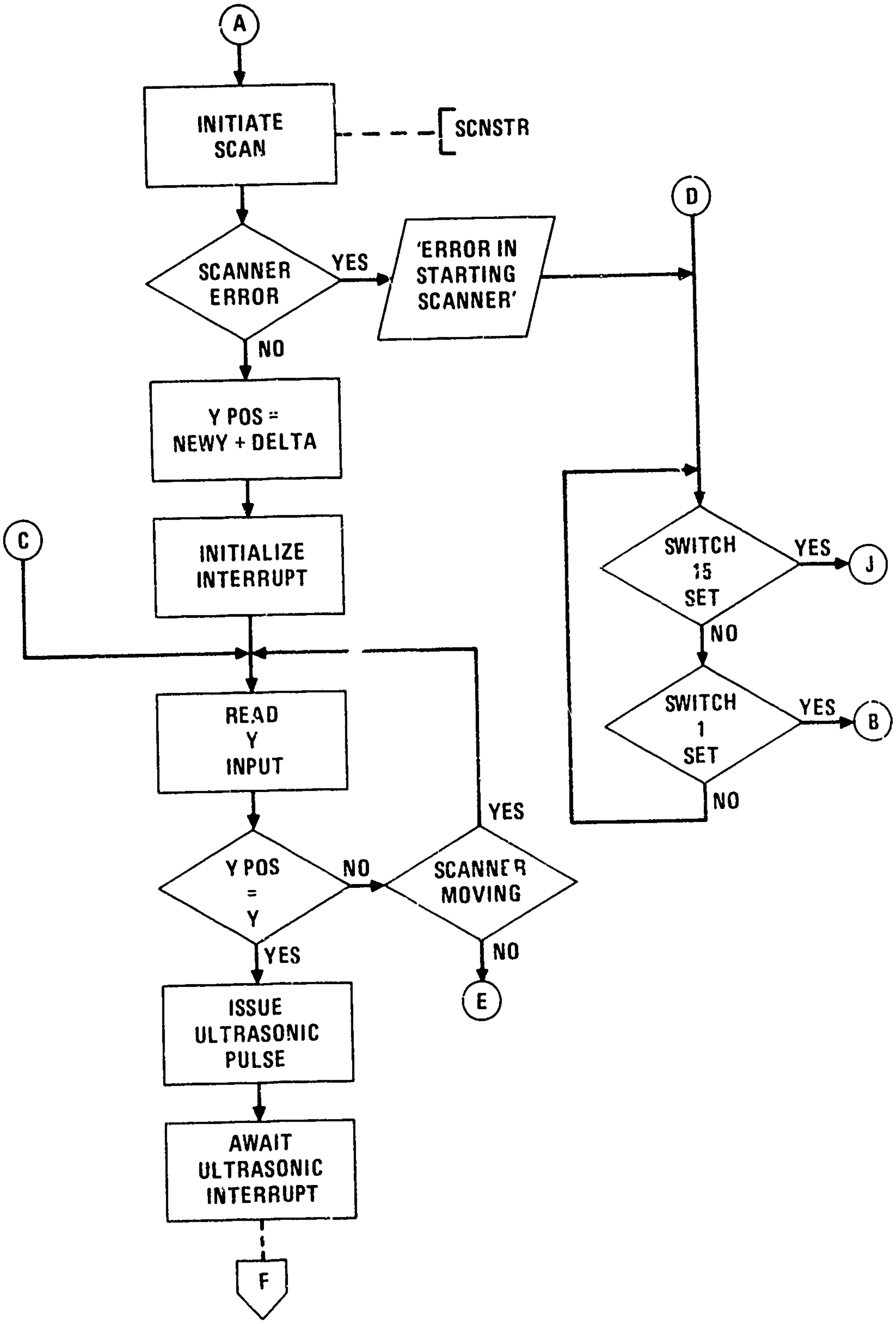


Figure E2. (Continued)

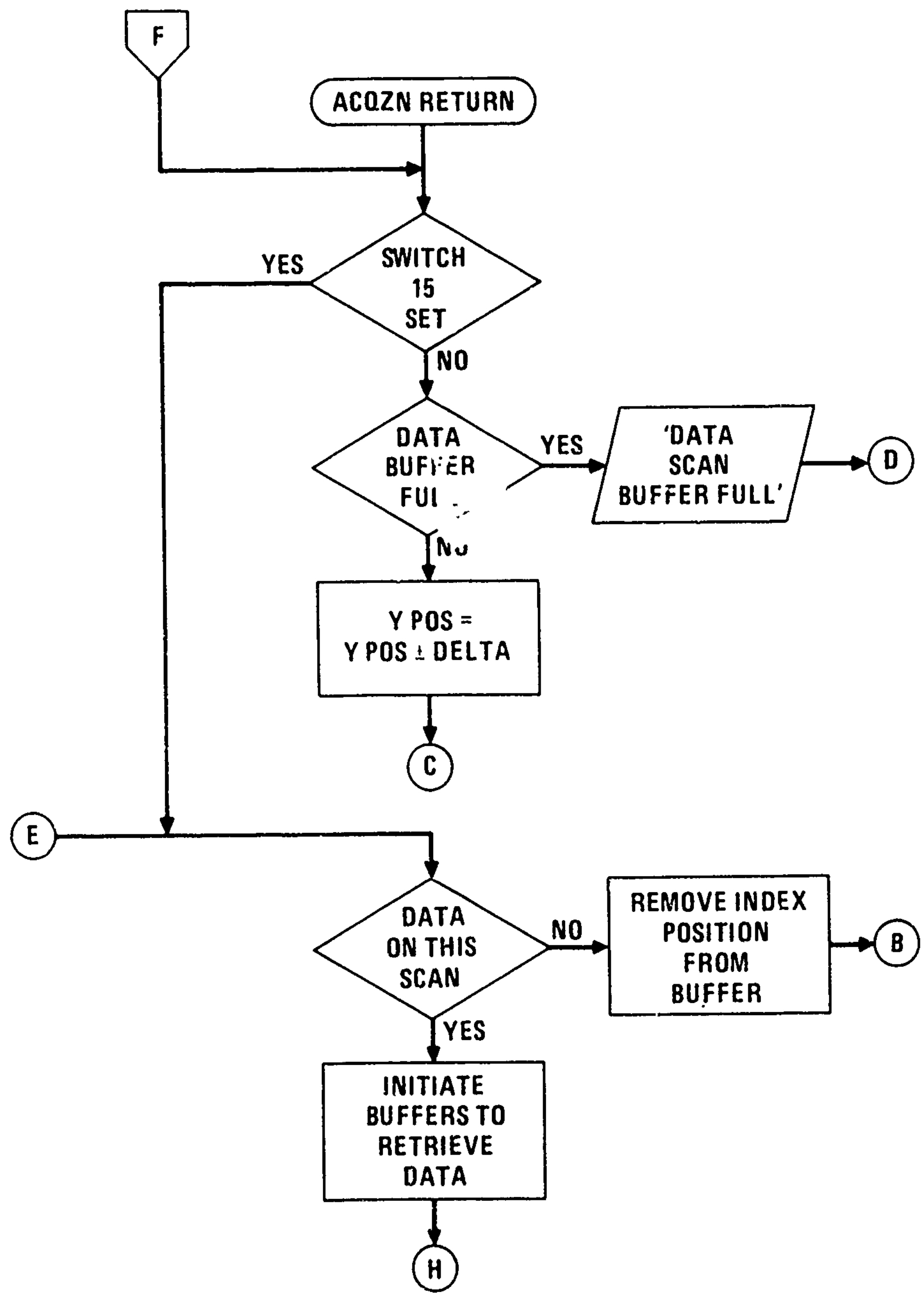


Figure E2. (Continued)

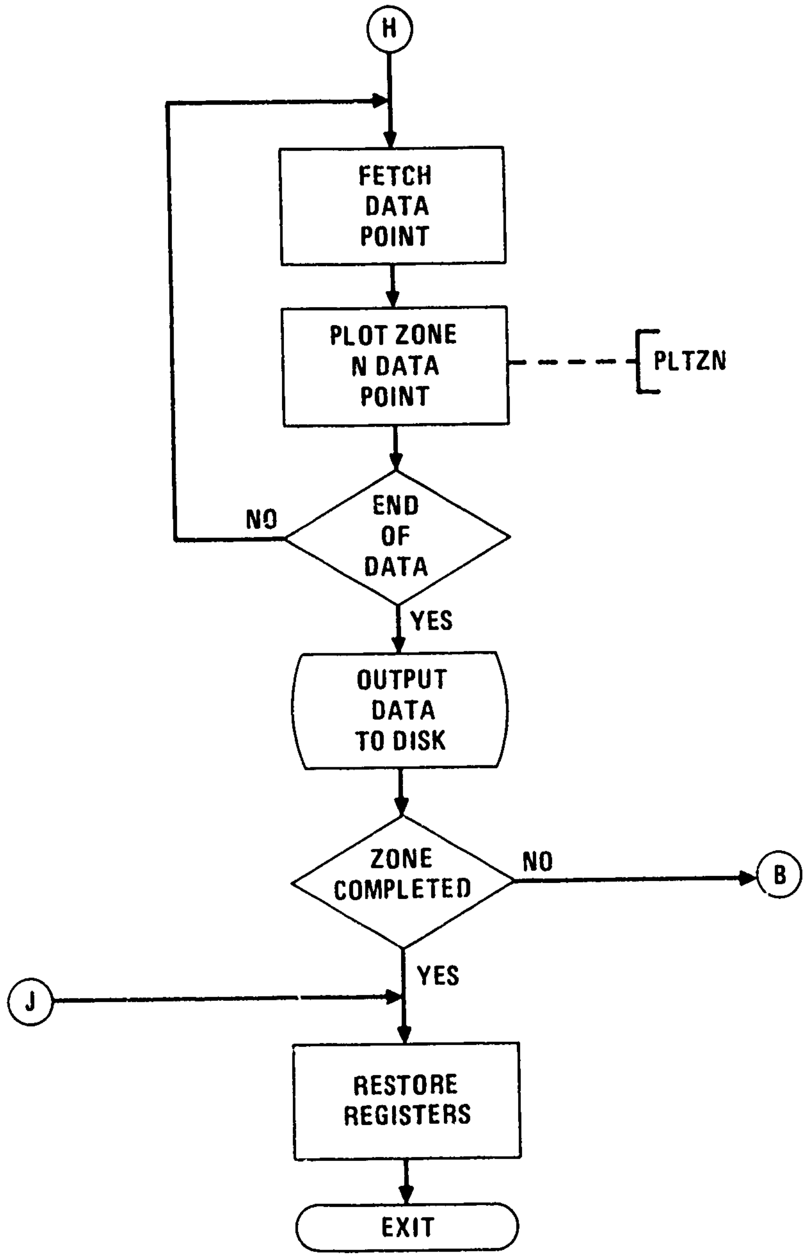


Figure E2. (Continued)

cycle. The first operation is to disable the interrupt. After this is done, the flag word (contents shown in Table E3) is checked for the presence of a top surface signal.

If a top-surface signal is present, the flag word, Y position, and time to the top surface are stored. Back surface and (or) flaw data are then saved, depending on the results of a minimal amount of real-time processing. After data has been moved to the buffers, the buffers are checked for depletion by calling DBCM.

The flow diagram is shown in Figure E3.

E.3.5 Data Acquisition-Interrupt Control Module for Zone-Ø Scanning

The Data-Acquisition-Interrupt Control Module for Zone-Ø Scanning (ACQZO) processes the interrupt generated at the end of each ultrasonic cycle. After disabling the interrupt, the flag word (bit 7 shown in Table E3) is checked for the presence of a top-surface signal from the back-up plate. If this top-surface signal is not present, the transducer is assumed to be over the part, and, depending on previous conditions, the boundary points, X-point, first Y-position over the part, and last Y-position over the part are saved. These parts are placed in the file described in Table E2. No data are saved on the flaw data file.

The flow diagram is shown in Figure E4 .

E.3.6 Real Time Disk Software

A chain of fourteen 256-word buffers is allocated for real-time disk I/O. The routine DSBUF allocates these buffers and various pointer tables.

The routine DBSTAT sets up the buffers for storage of data at the beginning of each scan index cycle. After the buffers have been depleted, the routine DBCM flags this to the CNTZNN routine. At the end of the scan index cycle, the routine EOSWM flushes the data buffers to disk.

The flow diagram for these routines is shown in Figure E5.

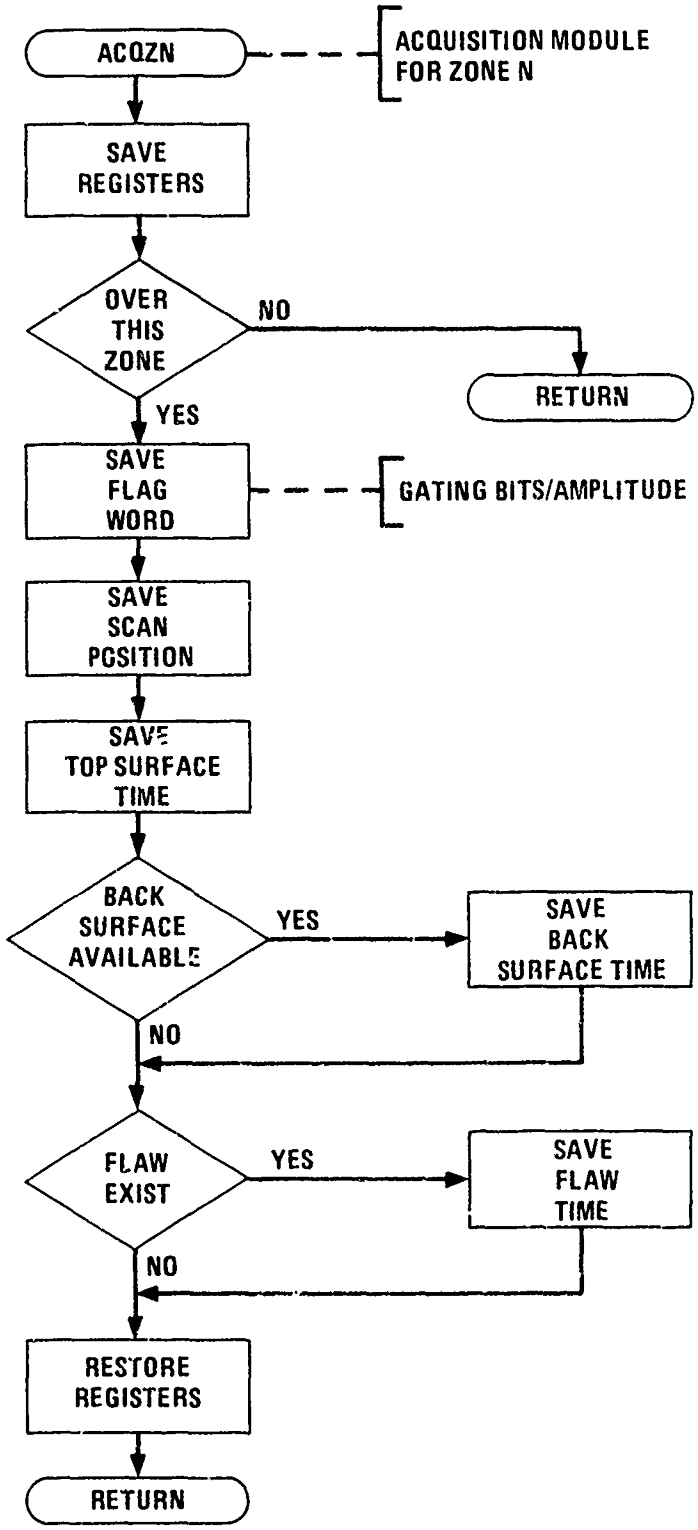


Figure E3. Flow Diagram For Data Acquisition Interrupt Control Module For Zone N Scanning

TABLE E3

CONTENTS OF DATA FLAG WORD

Bit	Condition When Set
15	Top Surface
14	Over the part
13	Used by software to indicate presence of back surface data
12	Used by software to indicate presence of flaw depth data
11-8	Flaw amplitude (Values range from 1-15)
7	Back-up plate
6-4	Not used
3-0	Used to indicate the number of flaw signals in the flaw gate.

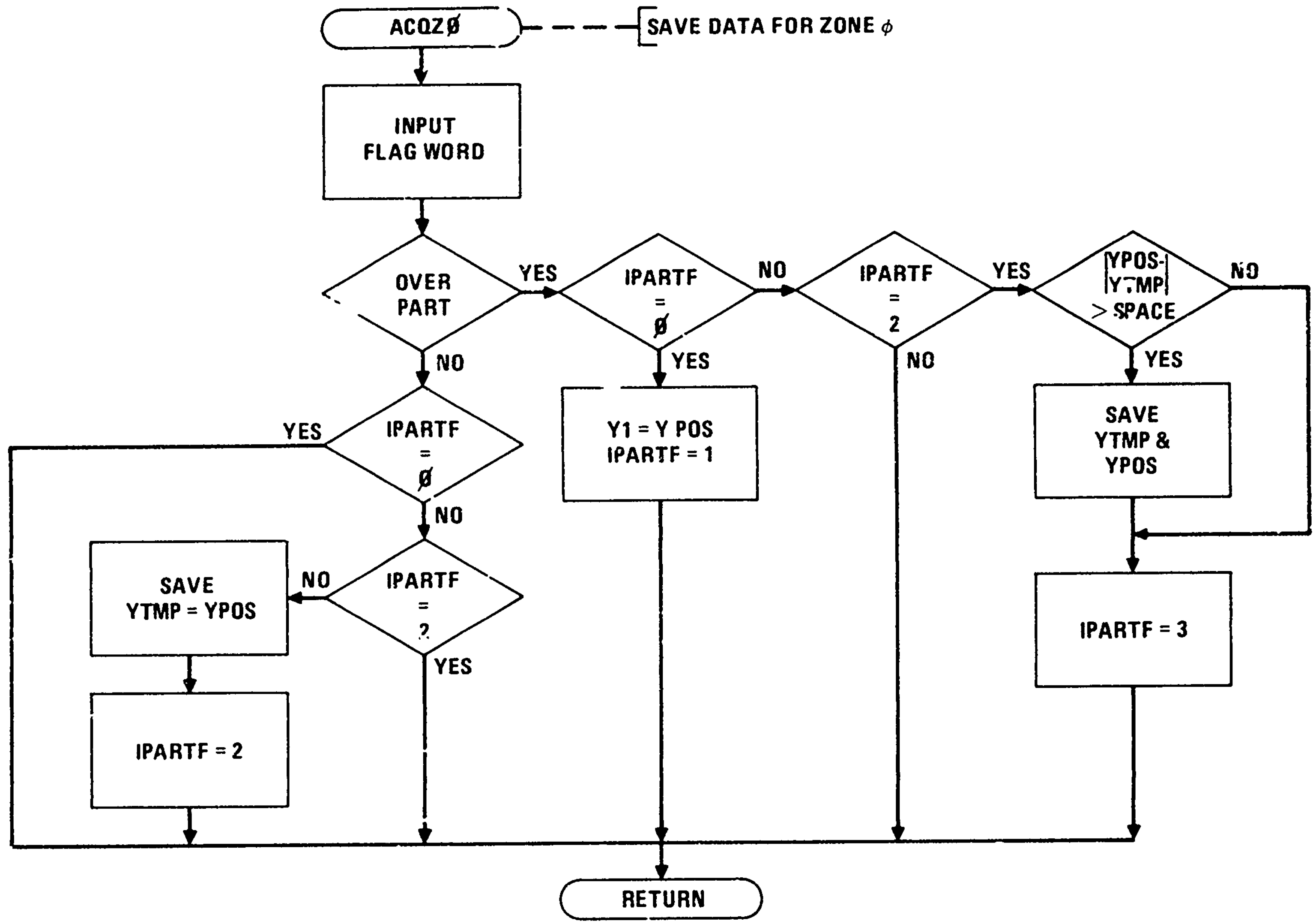


Figure E4. Flow Diagram For Data Acquisition Interrupt Control Module For Zone Ø Scanning

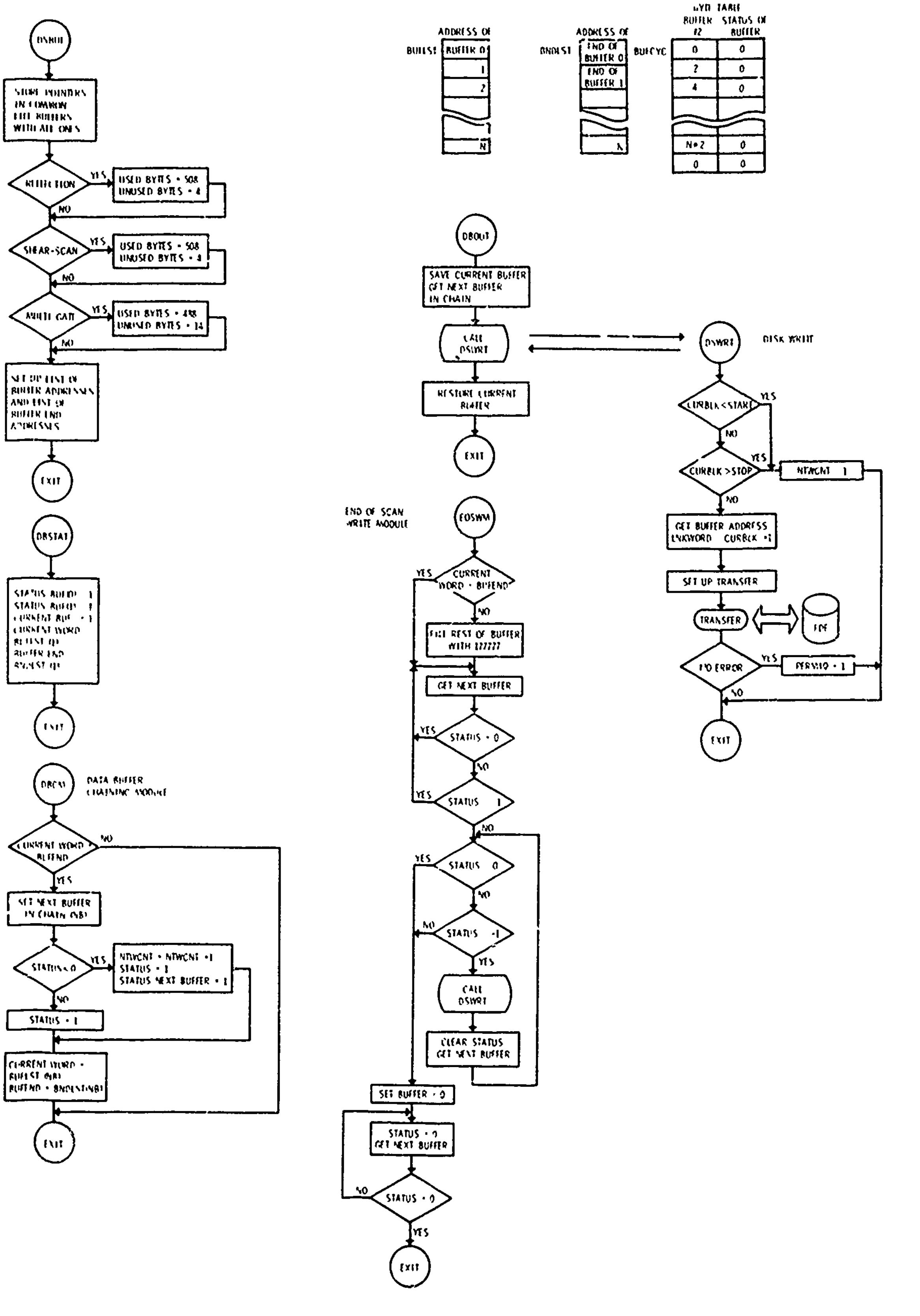


Figure E5. Flow Diagram for Real-Time Disk I/O

E.4 Overlay Structure

Table E4 lists the major subroutines called by the AUISCM program. Table E4 is followed by the routine name and a brief description. The names OPTLIB, TEKLIB, FDFLIB, and DALIB refer to libraries that are concatenated collections of routines used to perform a specific function, these routines are described next. Table E5 lists major routines called by POSTRPR, the post-processing routine; it is followed by a brief description of the routines used in the post-processing program.

<u>Overlay Ø</u> - Calls the following routines.

FDFLUK - Get START/STOP blocks of data file (ASSEMBLY)
FDFAR - Allocate flaw data file (ASSEMBLY)
GR - Get RUN
GSR - Get START/STOP blocks of specific run
LISTDK - List RUNS on data disk
DLTLR - Delete the last run.
FDFRLS - Release disk I/O linkage (ASSEMBLY)
OPTLIB
FDFLIB
TEKLIB

<u>Overlay 1</u> - Calls the following routines

OPTNCM - Modify the header blocks for run modes DATA and INITIAL
LITUCM - List on the scope the input options
SETCCM - Sets variables from header blocks in format required (i.e., convert integer to binary coded decimal)
SETHGT - Calculates the distance from the transducer to the back-up plate
DALIB
TEKLIB
OPTLIB

<u>Overlay 2</u> - Calls the following routines

DGRDCM - Draws the grid
DLABEL - Labels the two axes
DIDCM - Writes the labels below the grid
TEKLIB

TABLE E4

RESIDENT MAIN CALL TABLE

RESIDENT MAIN
FDFINT
LINK
COMMONS

OVL Ø	OVL 1	OVL 2	OVL 3	OVL 4	OVL 5	OVL 6	OVL 7
OVLØCM	OVL1CM	OVL3CM	OVL4CM	OVL5CM	OVL6CM	OVL7CM	OVL8CM
FDFLUK	OPTNCM	DGRDCM	CNTZNØ	CNTZNN	CNTRDX	CNTCUR	POCRAD
GR	LTIVCM	DLABEL	ACQZØ	ACQZN	ACQRDX	ACQCUR	POCCUR
GSR	SETCCM	DIDCM	PLTZØ	RTACT	XYVECT	PLTRDX	CNTRDX
LISTDK	SETHGT		BNDSVE	NEWPT	PLTRDX	RTACTX	CNTCUR
DLTLR			PLTBND	PLTZN	RTACTX	DSBFCM	ACQRDX
FDFRLS			DSBFCM	NORMAL	DSBFCM	AUTOCL	ACQCUR
				PLOTTR	AUTOCL		PLTRDX
				AUTOCL			XYVECT
				DSBFCM			RTACTX
							DSBFCM
							AUTOCL

AUISCM MAJOR ROUTINES IN EACH OVERLAY

TABLE E5

POSTPR CALL TABLE

- POSTPR
  FDFINT
  LINK
  COMMONS
  - OVINIT
    - FILTER
    - ZNCNT
  - OVDRAW
    - DIAGRM
    - DGRDPR
    - DLABEL
    - DSCALE
  - OVPLOT
    - ROMAN
    - PLTCNT
    - AMPLTD
    - BACKPT
    - PLTZN1
    - CONSEC
    - SCLINE
    - WRTREP
    - GAPPER
    - OPT9
    - PROFIL

Overlay 3 - Calls the following routines.

OVL4CM - Controls initialization and input of boundary points
CNTZNØ- Control module for Zone-Ø scanning (ASSEMBLY)
ACQZØ - Data-acquisition module for Zone-Ø scanning (ASSEMBLY)
PLTZØ - Plots boundary points from Zone-Ø scanning
BNDSUE - Saves boundary points obtained from Zone-Ø scanning.
PLTBND - Plots retrieved boundary points for the upcoming Zone N-scan
FDFLIB
DALIB
TEKLIB
OPTLIB

Overlay 4 - Calls the following routines

OVL5CM - Control routine for normalization and Zone-N scanning
CNTZNN - Control module for data acquisition for the Zone-N scanning (ASSEMBLY)
ACQZN - Data-acquisition module for Zone N scanning (ASSEMBLY)
RTACT - Transforms encoder coordinates to coordinates on the part.
NEWPT - Retrieves boundary points for each scan line and places scanner in initial scanning position.
PLTZN - Plots top-surface and potential-flaw data for Zone-N scan.
NORMAL - Seeks normal at an operator input position by using bit 15 of the flag word.
PLOTTR - Performs near real-time processing on data from the most recent scan line (ASSEMBLY)
AUTOCL - Performs automatic-calibration function
DSBFCM - Allocates the chain of buffers for disk I/O, also contains entry points for the following: (ALL ASSEMBLY)
DBSTAT - Sets buffer status
DBCM - Checks buffer status
EOSWM - Flushes buffers at end of scanner index cycle
DSWRT - Performs transfer of data to disk
DALIB
OPTLIB
FDFLIB
TEKLIB

Overlay 5 - Calls the following routines

OVL6CM - Controls input and retrieval of normals and end points for vector-radius scan.
CNTRDX - Control module for data acquisition for vector-radius scanning (ASSEMBLY)
ACQRDX - Data-acquisition module for vector-radius scanning (ASSEMBLY)
XYVECT - Control speed and movement of X and Y motors for vector scanning
PLTRDX - Plots top-surface and potential flaw data for vector-radius scan
RTACTX - Transforms encoder coordinates to coordinate on the part for vector-radius scanning.
DSBFCM - Previously described
AUTOCL - Previously described
TEKLIB
FDFLIB
OPTLIB
DALIB

Overlay 6 - Calls the following routines.

OVL7CM - Controls input and retrieval of points necessary to scan curved-radius areas.
CNTCUR - Control module for data acquisition for curved-radius scanning (ASSEMBLY)
ACQCUR - Data-acquisition module for curved-radius scanning (ASSEMBLY)
PLTRDX - Previously described
RTACTZ - Previously described
DSBFCM - Previously described
AUTOCL - Previously described
DALIB
OPTLIB
FDFLIB
TELKIB

Overlay 7 - Calls the following routines.

OVL8CM - Controls input and retrieval of points necessary to scan pocket areas
POCRAD - Controls data acquisition for vector-radius scan in a pocket area

POCCUR - Controls data acquisition for curved-radius scan in a pocket area.

Previously described:

CNTRDX	XYVECT
CNTCUR	RTACTX
ACQRDX	DSBFCM
ACQCUR	AUTOCL
PLTRDX	

FDFLIB
TEKLIB
OPTLIB
DALIB

<u>OPTLIB</u> - This library contains the routines used to perform I/O with the teletype

RDIN - Read in a fixed-point number
RDFPN - Read in a floating-point number
RDASC - Read in a string of alphanumerics
YESNO - Read in a YES (ON) or a NO (OFF) keyboard entry
CHRSCN - Scan through a series of characters and remove blanks.
LJSTFY - Left justifies a string of characters to computer fixed-point words
DTB - Convert BCD numbers to binary (ASSEMBLY)
BTD - Convert binary number to BCD (ASSEMBLY)

<u>TEKLIB</u> - This library contains routines to facilitate writing and drawing graphs on the Tektronic 4010 Storage Scope.

AXIS - Draws grid
ABOR - Labels grid
PLTPAK - Performs I/O with the scope, has entry points to draw line, plot a dot (ASSEMBLY)
PGEJ - Erase screen
HCPE - Copy screen to Tektronic 4610 Hardcopy unit
FLUSH - Flushes the 96-character buffer associated with the 4010 scope
WAITF - Flushes the 96-character buffer then waits for a key to be pressed on the 4010 scope
CRTIO - Output a character to scope (ASSEMBLY)

FDFLIB - This library contains routines to communicate with the flaw data file (DK1)

FDFINT - Initialized FDF (ASSEMBLY)
FDFAR - Allocate FDF (ASSEMBLY)
FDFLUK - Get START/STOP blocks of FDF (ASSEMBLY)
FDFDR - Deletes an old FDF (ASSEMBLY)
FDFRLS - Release disk I/O linkage (ASSEMBLY
BLKIO - Read/write N number of words from/to block M
FDFOUT - Writes a block of data to the FDF by interfacing with the DSWRT routine (ASSEMBLY)
FDFIN - Reads a block of data from the FDF by interfacing with the FDFRD routine (ASSEMBLY)
DSWRT - Writes data to FDF (ASSEMBLY)
FDFRD - Reads data from FDF (ASSEMBLY)

DALIB - This library contains routines that interface with the scanner

RDXYZ - Reads encoder positions for X, Y, and Z (ASSEMBLY)
RDRT - Reads encoder positions for tilt and rotate (ASSEMBLY)

MOVSCN - All are ASSEMBLY

MOVX - Moves X to a specified location
MOVY - Moves Y to a specified location
MOVZ - Moves Z to a specified location
MOVR - Moves Rotate to a specified location
MOVT - Moves Tilt to a specified location

SCNCNT - Scanner control module has entry points for: (All are ASSEMBLY)

SCNITZ - Initialize scanner
SCNSTR - Start scanner
SFDBK - Handles feedback for scanning axis
INDEX - Indexes scanner
IFDBK - Handles feedback for index axis

SDCMOD - Speed control module (ASSEMBLY)

SETSPD - Output initial speed (ASSEMBLY)

P st-processing overlays

OVINIT - Calls the following routines

FILTER - Performs initialization function and operator selection of options
ZNCNT - Finds zones for the chosen run number

OVDRAW - Calls the following routines

DIAGRM - Controls scaling, labeling, titling and drawing the grid.
DGRDPR - Draws the grid
DLABEL - Labels the two aces
DSCALE - Selects the scales for the grid from the input options, optimizes the grid usage by rotating X and Y scales.

OVPLOT - Calls the following routines

PLTCNT - Controls the output from the amplitude filter, depth filter, and consecutive pulses filter
AMPLTD - Calculates amplitude of flaw signal from bits 8-11 of flag word
BACKPT - Controls output for pulses having back surface signals
PLTZNI - Plots flaw data on 4010 scope
CONSEC - Accumulates consecutive pulse intervals for each scan line.
SCLINE - Finds start and stop block numbers for each scan line
WRTREP - Writes report data to 4010 scope
GAPPER - Transfers consecutive pulse interval over a gap where a pulse could be missing
OPT9 - Controls the adjacent scan line filter
PROFIL - Runs statistical analysis on the distribution of amplitudes for each consecutive string.

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SUPPLEMENTARY

INFORMATION

AD-A072677 ~~AD-A1181073~~

DEPARTMENT OF THE AIR FORCE
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES (AFSC)
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

REPLY TO ATTN OF: MLLP

27 October 1983

SUBJECT: AFML-TR-79-4016

TO: Defense Technical Information Center
ATTN: DDAC (Mr J. E. Condiff)
Cameron Station
Alexandria VA 22314

1. Reference is made to the telephone conversation on 27 October 1983 between Mr Condiff of your organization and K. D. Shimmin of AFWAL/MLLP.

2. A review of subject Technical Report has resulted in the determination that the following changes are necessary:

a. The correct title should be as it appears in Item 4 of the DD Form 1473.

b. The apparent proprietary notice on Figure D10, page 150, should be deleted.

c. The notice at the bottom of the cover, concerning non-release under the Freedom of Information Act, should be deleted.

Kenneth D. Shimmin

KENNETH D. SHIMMIN
Nondestructive Evaluation Branch
Metals and Ceramics Division

File